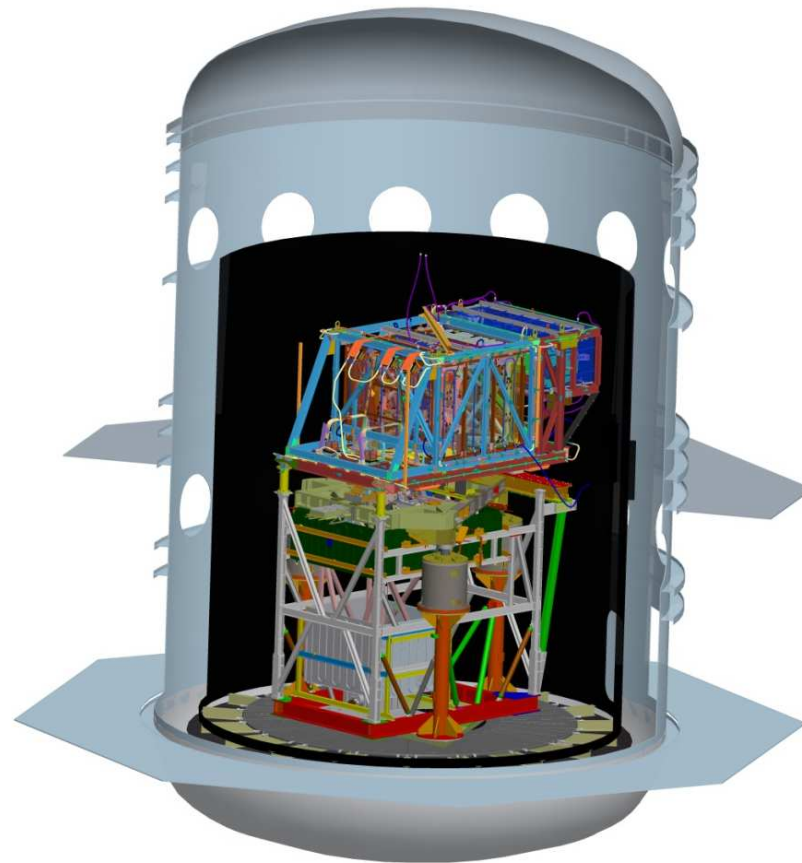


# **James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) Cryo-Vacuum (CV) Test Campaign Summary**

Presenter:  
Calinda Yew

Other Co-Authors:  
Paul Whitehouse  
Yan Lui  
Kimberly Banks

29<sup>th</sup> Space Simulation Conference  
NASA Goddard Space Flight Center  
(GSFC)



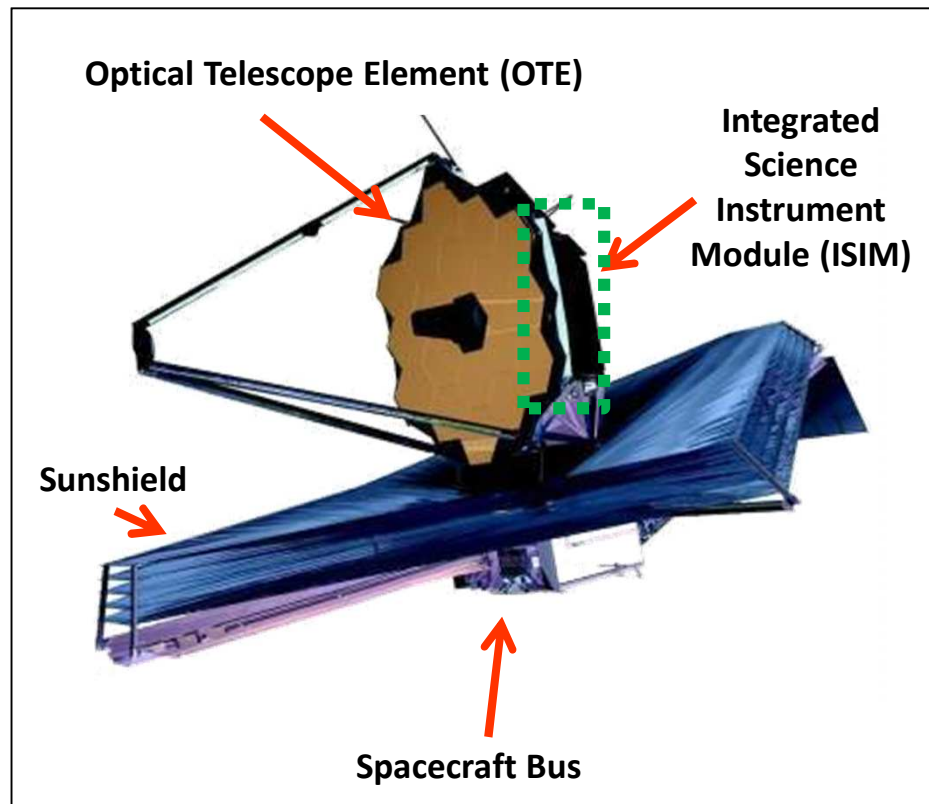
# Agenda

- JWST Mission Overview
- CV Test Objectives
- Test Configuration Overview
- Test Requirements
- CV Overall Test Summaries
- Chamber Performance
- Instrumentation Performance / Improvements
- Lessons Learned



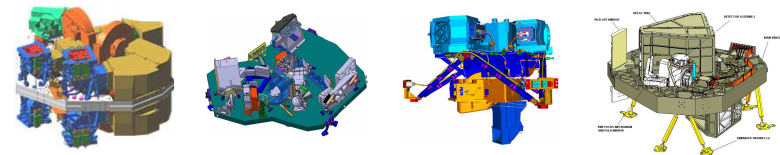
# JWST Mission Overview

*The Integrated Science Instruments Module (ISIM) houses all the science instruments for the James Webb Space Telescope (JWST)*



## JWST Mission Objective

Study the origin and evolution of galaxies, stars & planetary systems:  
*Optimized for infrared observations*  
( $0.6 - 28 \mu\text{m}$ )



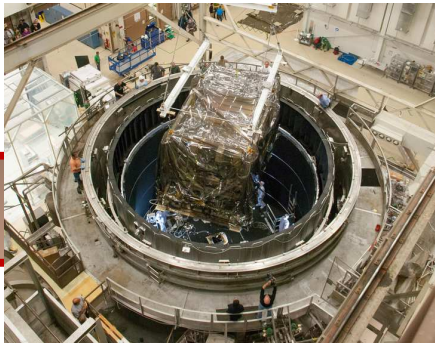
## Four Science Instruments (ISIM)

- Near Infrared Camera (NIRCam)
- Near Infrared Spectrograph (NIRSpec)
- Mid-Infrared Instrument (MIRI)
- Fine Guidance Sensor (FGS)



# CV Test Objectives Summary

## CV1 & CV2



CV1: Risk Reduction  
CV2: Assess ISIM config & start system-level verification

## Vibe, Acoustics, EMI



## CV3



CV3: Verify ISIM in its final configuration after environmental exposure and provide a post-environmental performance baseline (including critical ground calibrations for science data processing in flight)

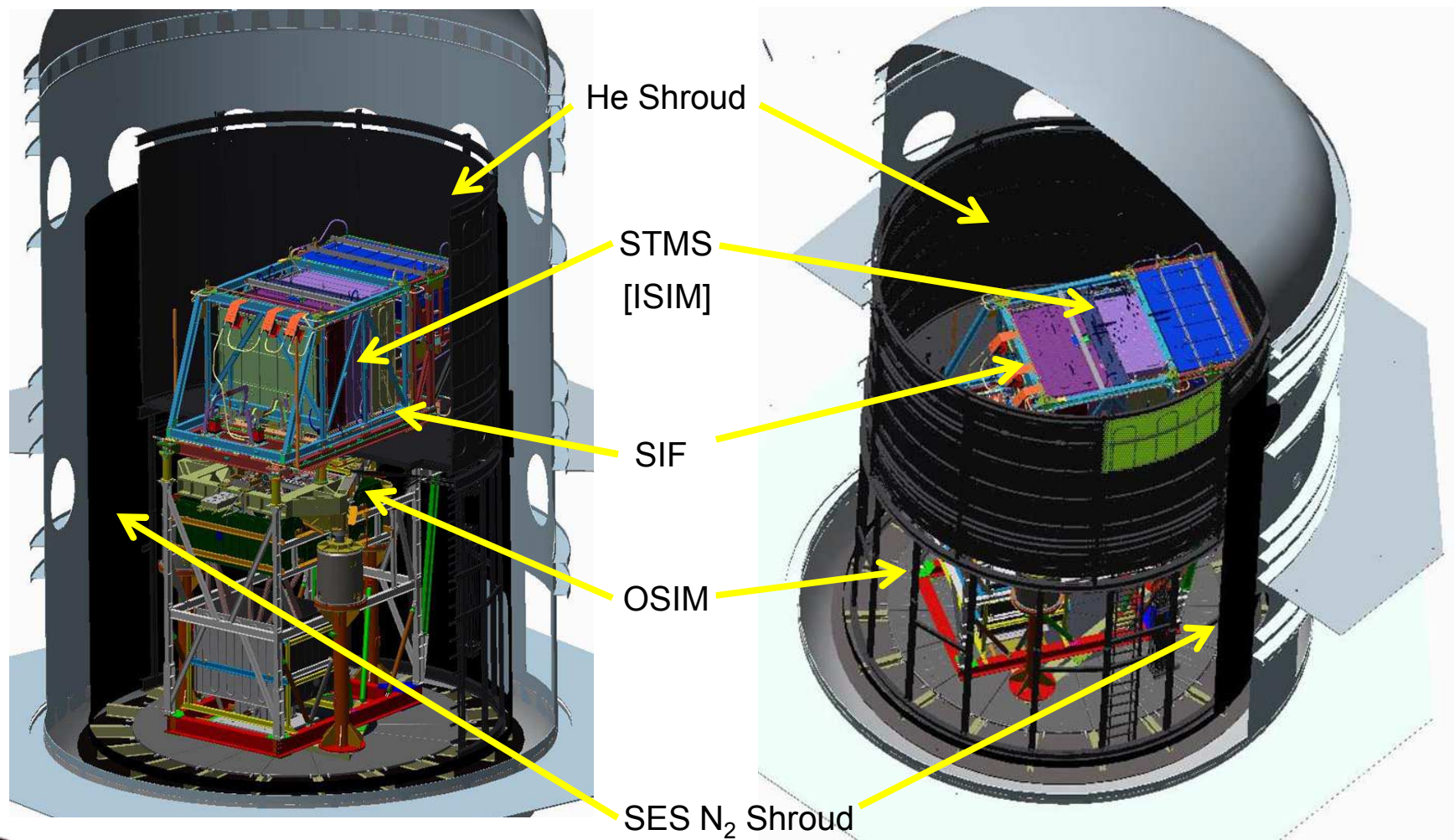


**OTIS I&T**  
**Oct 2018**  
**Launch**





# ISIM CV Testing Test Configuration





# ISIM Test Set-Up



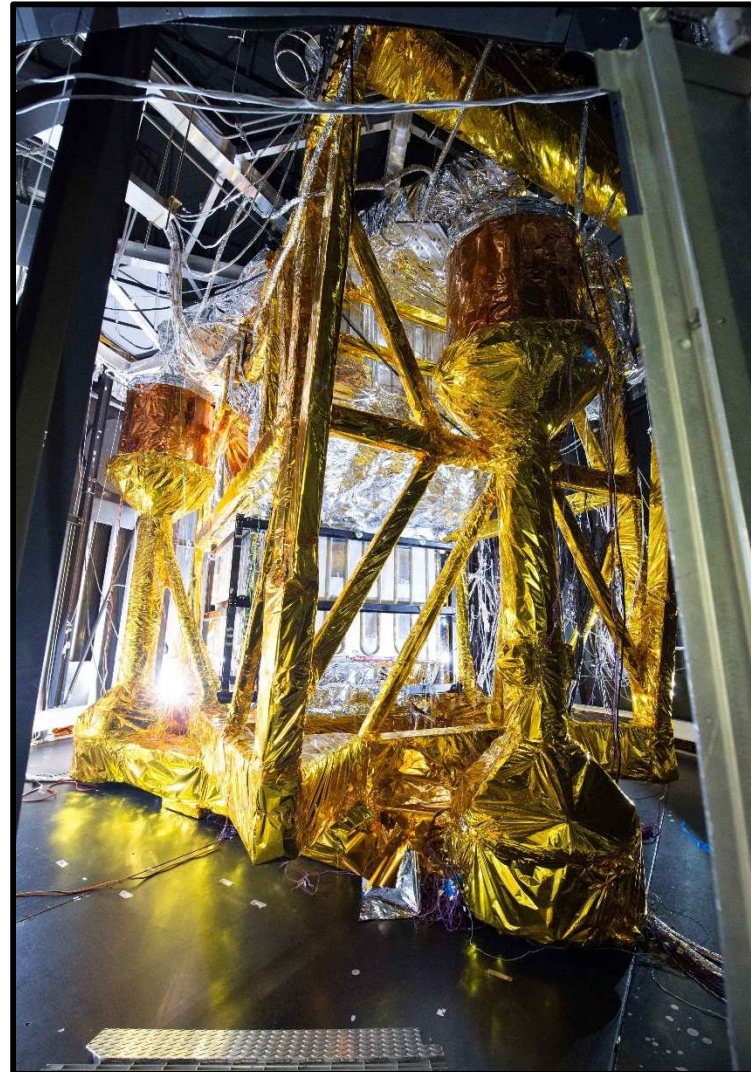


# ISIM Test Set-Up



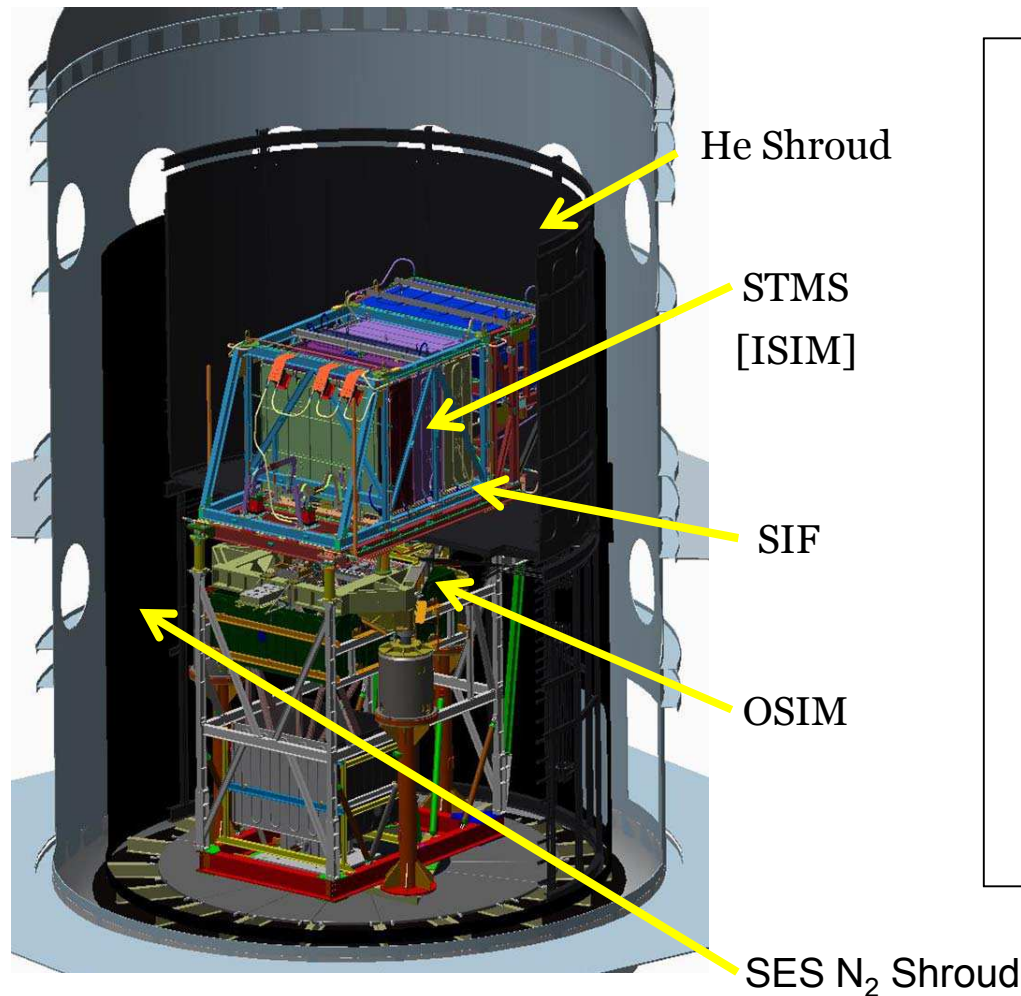


# ISIM Test Set-Up





# Facility Requirements for ISIM CV3



## Thermal Zones

- SES Shroud ( $\text{LN}_2 \rightarrow \text{GN}_2$ )
  - Helium Shroud (5 GHe ckts)
  - 41 Cryopanels
    - 4 TCUs
    - 6  $\text{LN}_2$ -only lines
    - 5 GHe circuits
  - 171 Heater circuits
    - 9 Heater Racks
    - 15 LS-336s
- 10 helium zones are cooled using a 1.0 kW helium refrigeration system

## ISIM Test Summary CV1 – CV3

Item		CV1	CV2	CV3
Pump-down Date		8/29/2013	6/17/2014	10/27/2016
He skid Shutdowns		6	3	1
Power outages		1	3	0
Total days of testing		73	116	109
Total consumables	LN <sub>2</sub> (gallons)	520K	1.03M	935K
	Helium	20 bottles	20 bottles	20 bottles



# Instrumentation Reliability

Instrumentation included >1000 temperature sensors total for all three CV tests

Temp Sensors	CV1	CV2	CV3
T Thermocouples	366	396	375
Silicon Diodes	242	246	248
Platinum Resistance Thermometers (PRTs)	242	248	248
Cernox sensors	80	80	108
Heater control sensors	191	193	193
<b>Total:</b>	<b>1121</b>	<b>1163</b>	<b>1172</b>
<b>% Failure:</b>	<b>4.6</b>	<b>3.2</b>	<b>1.9</b>

Total failure rate for monitoring sensors improvement ~1.3% each test



## Chamber Vacuum Performance: Pumpdown CVs

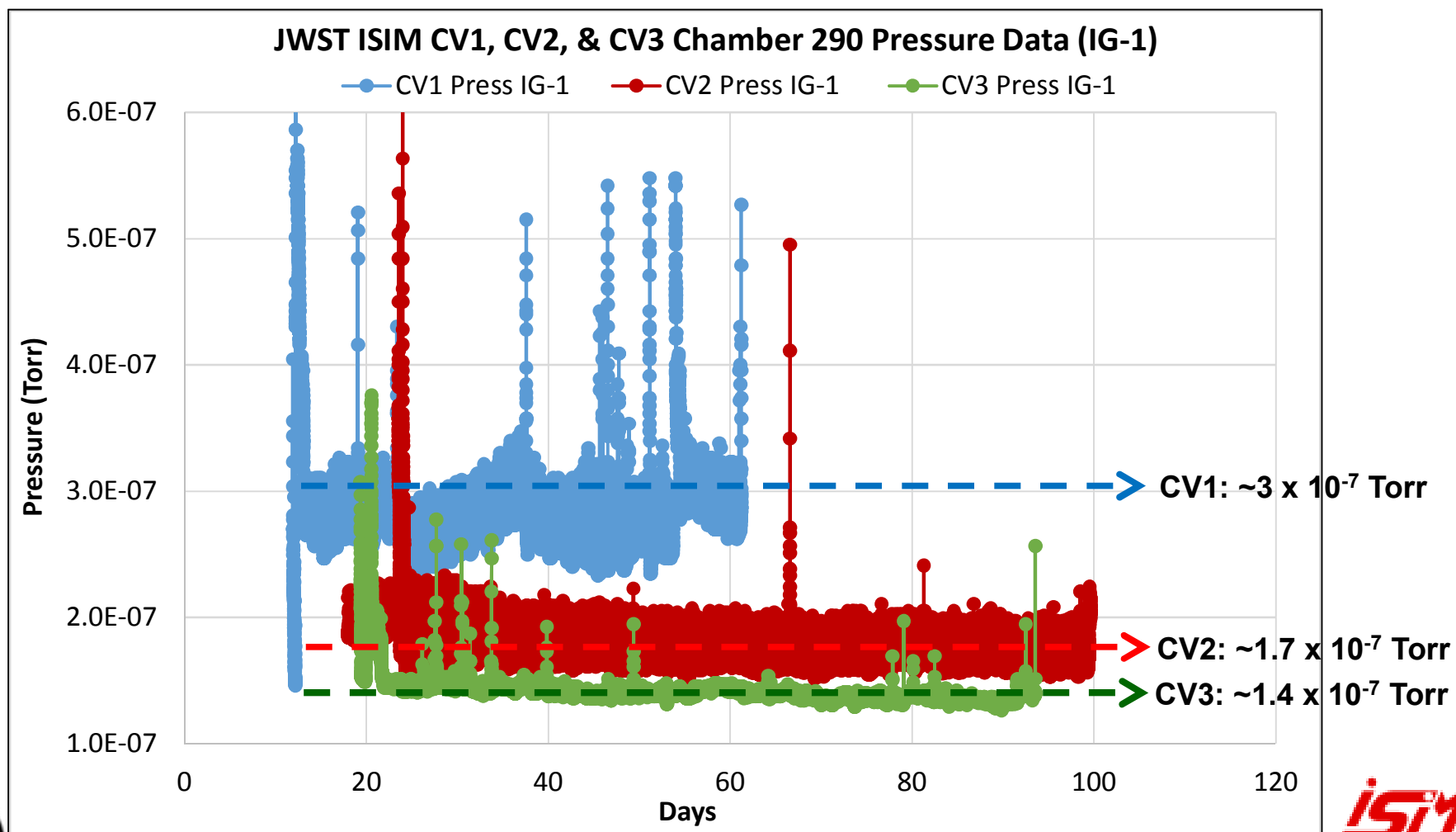
Pressure (Torr)	Time from start CV1	Time from start CV2	Time from start CV3
$5.0 \times 10^{-5}$	29 hrs (1.2 days)	7.8 hrs (0.33 days)	3.5 hrs (0.15 days)
$1.0 \times 10^{-5}$	35 hrs (1.5 days)	20.6 hrs (0.86 days)	11.1 hrs (0.46 days)
$5.0 \times 10^{-6}$	46 hrs (1.9 days)	27 hrs (1.13 days)	24.5 hrs (1.02 days)
$1.0 \times 10^{-6}$	108 hrs (4.5 days)	101 hrs (4.2 days)	88.2 hrs (3.7 days)
$5.0 \times 10^{-7}$	128 hrs (5.3 days)	160 hrs (6.7 days)	177.6 hrs (7.4 days)





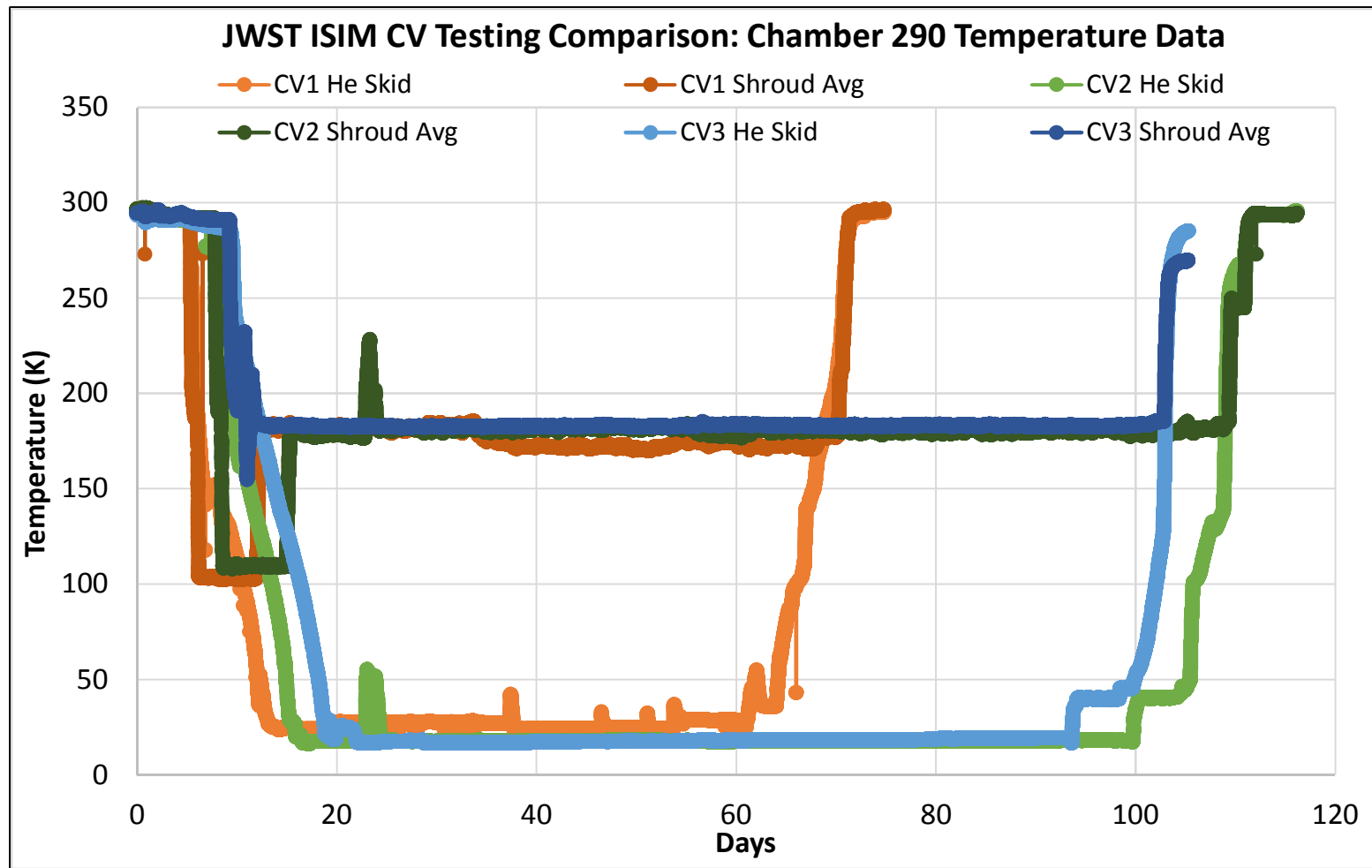
## Chamber Vacuum Performance: CV1 vs. CV2 vs. CV3

During steady-state (cool-down & warm-up omitted), vacuum pressure improved with each CV test



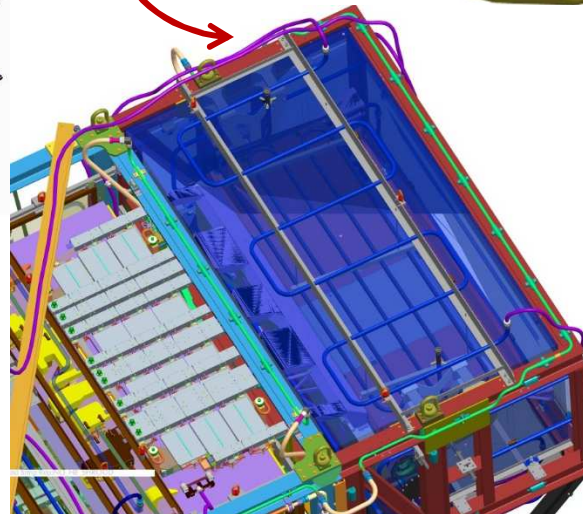
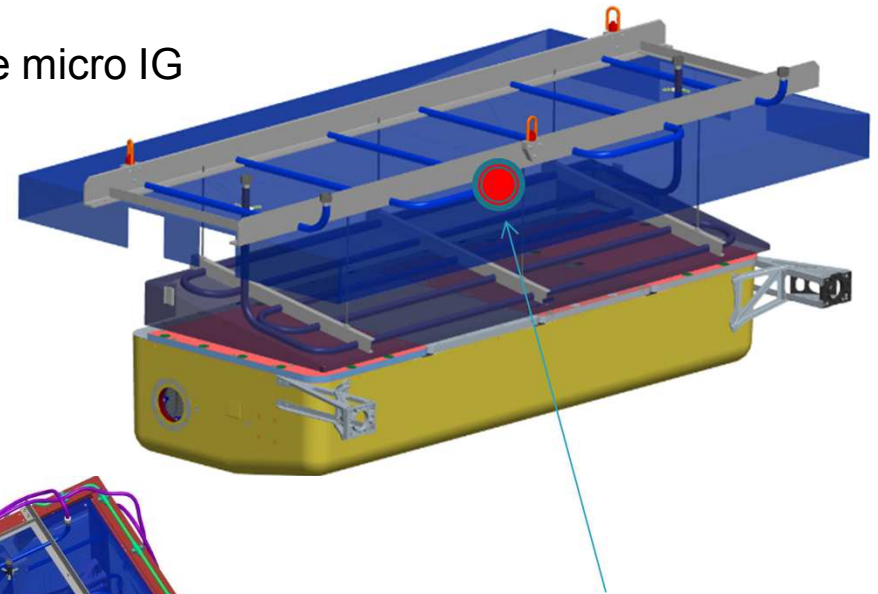
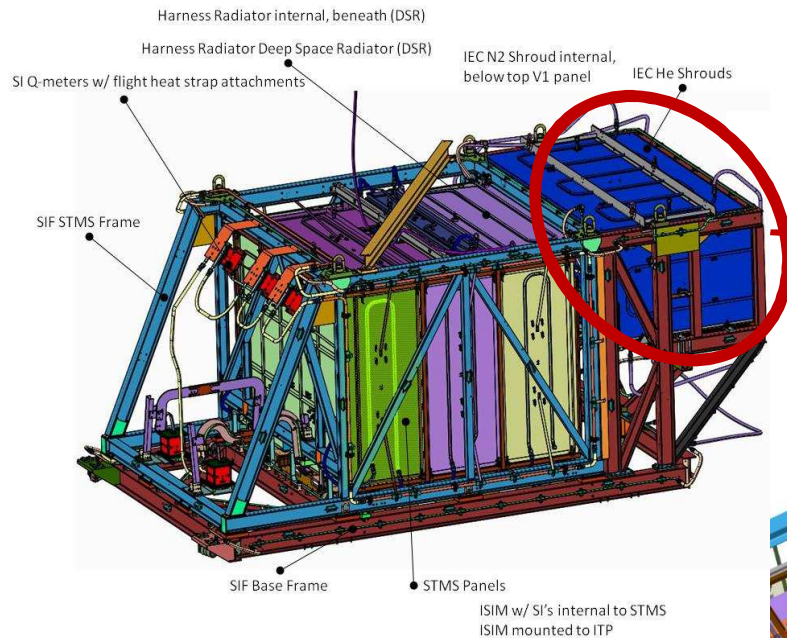
# Shrouds Temp Performance CV1 vs. CV2 vs. CV3

At steady state: Helium shroud average achieved:  $18\text{K} \pm 1\text{K}$  ||  $\text{LN}_2$  shroud average:  $180\text{K} \pm 3\text{K}$



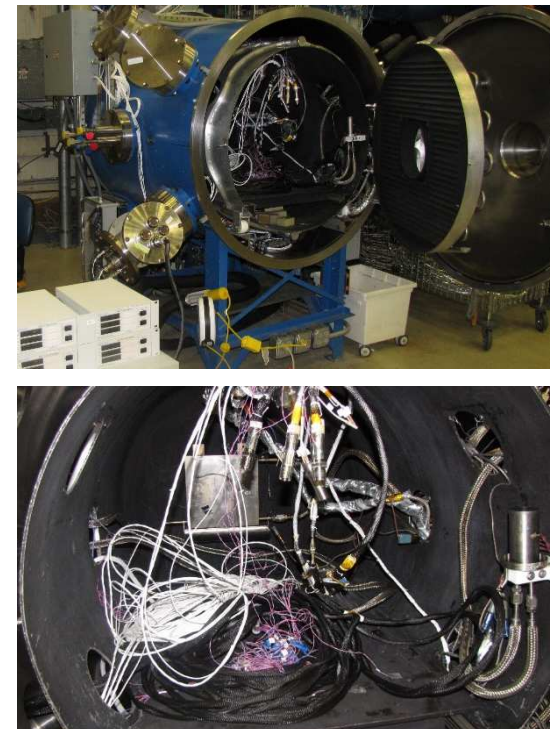
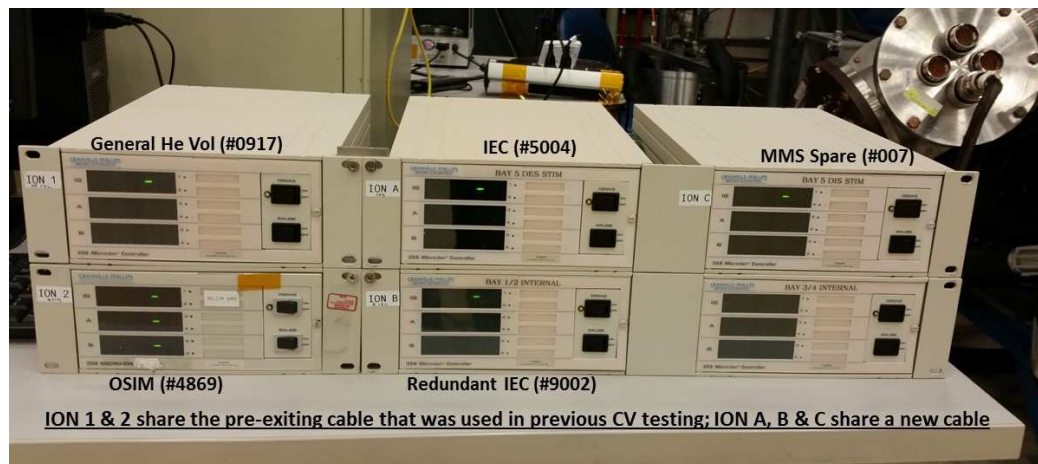
## Notable Facility Improvements CV1 → CV2 → CV3

- Micro Ion Gauges (IGs) for the ISIM Electronics Compartment (IEC)
  - CV2: moved one to IEC shroud volume
  - CV3: added redundant IEC shroud volume micro IG



## Notable Facility Improvements CV1 → CV2 → CV3

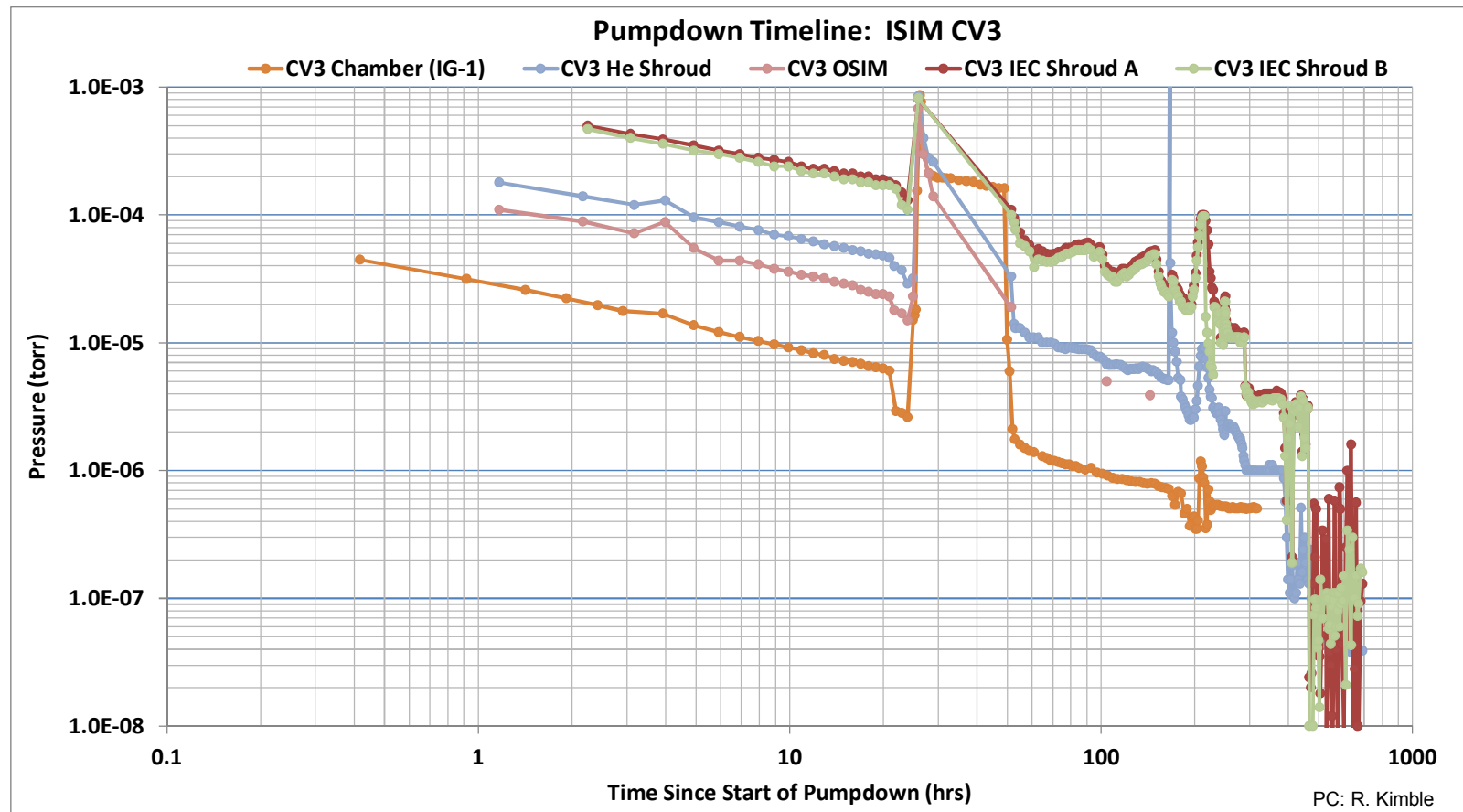
- Redundant micro ion gauge for IEC
- During check-out of the CV2 IGs, it was discovered that the extension used for the IEC IG was the root cause for the erratic and unreliable readings (per the spec sheet, maximum cable length allowable is 50')
- Cross-calibration of existing and new harnesses (+1 new redundant IEC micro IG) was performed in Facility 281





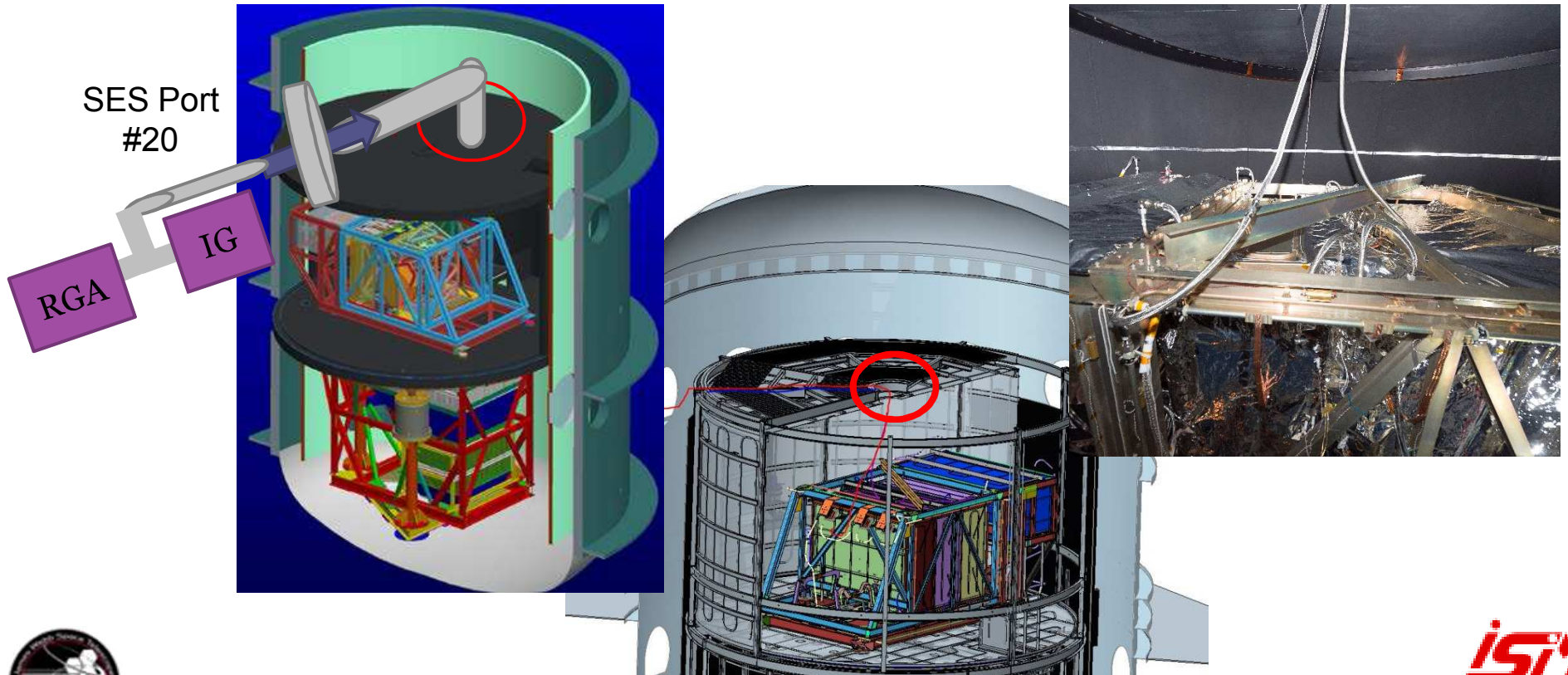
## Notable Facility Improvements CV1 → CV2 → CV3

- Redundant micro ion gauge for IEC



## Notable Facility Improvements CV1 → CV2 → CV3

- Residual Gas Analyzer (RGA) to monitor STMS inside helium shroud
  - CV2: Added a RGA using flex lines into helium volume
  - CV3: Bought new calibrated RGA; used SS tubing instead of flex lines



## Notable Facility Improvements CV1 → CV2 → CV3

### Two objectives of the RGA efforts

1. Measure helium test parasitic heat load on the MIRI Cooler
2. Verify MIRI cooler helium leak rate post-vibe to meet end-of-life (10.85) requirement not to exceed 1%

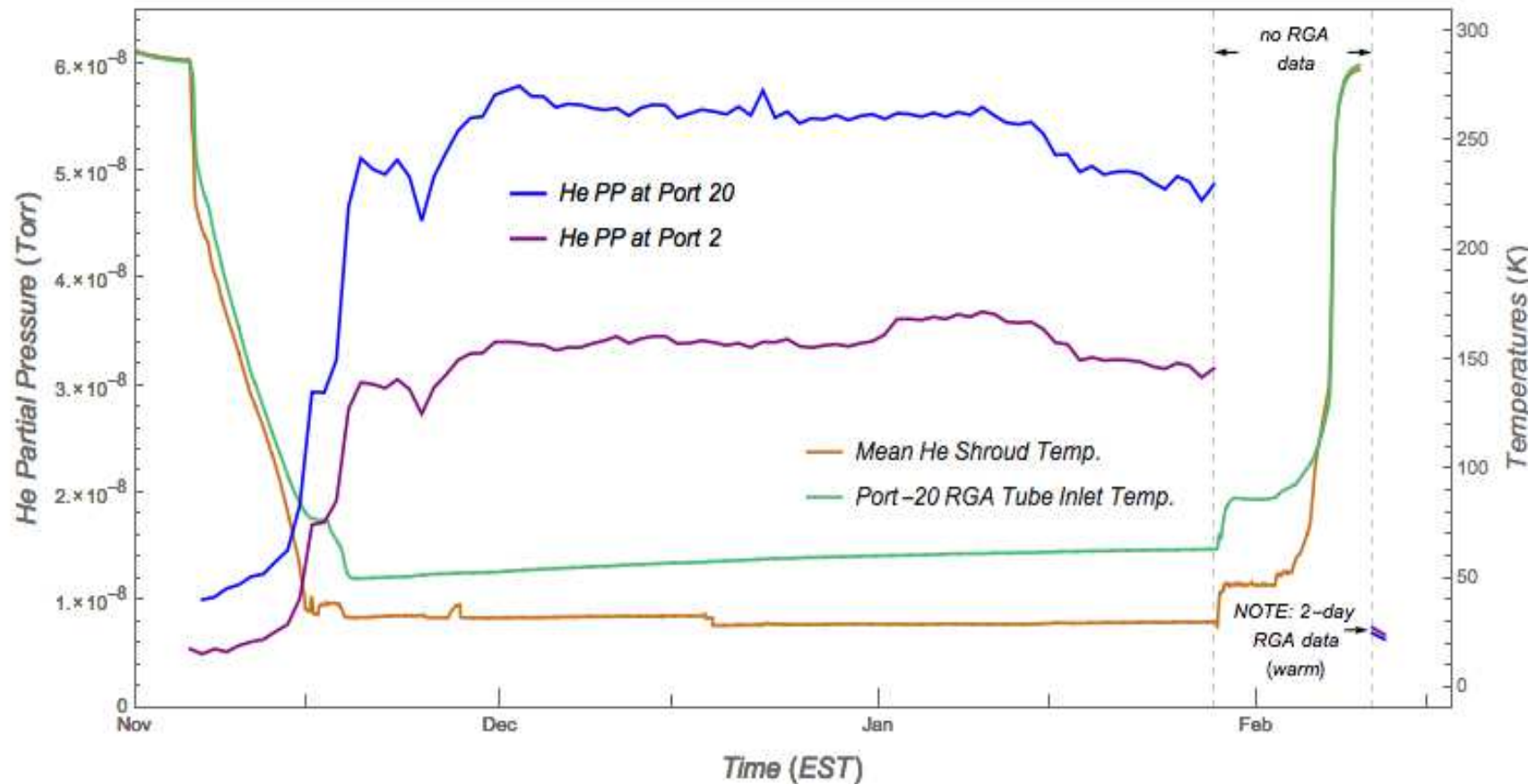


- Verified the heat load on the MIRI Cooler – less than 0.7 mW: Good!
- Helium background in chamber too high to verify cooler leak rate



# Notable Facility Improvements CV1 → CV2 → CV3

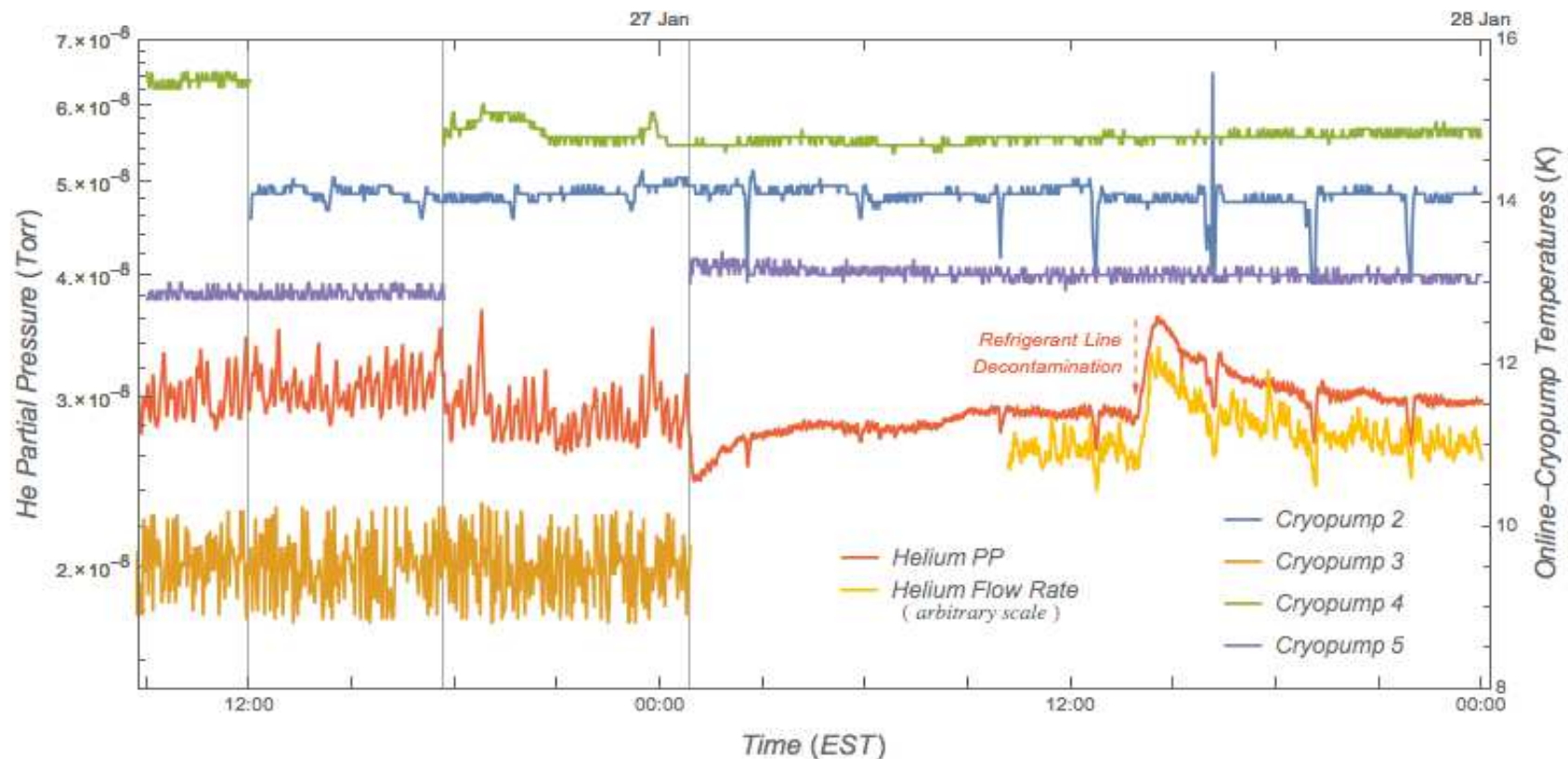
## Average Daily Helium Background in CV3





## Notable Facility Improvements CV1 → CV2 → CV3

Chamber cryo-pump temperatures & helium partial pressures show a correlation that affects background helium levels within the chamber



# Lessons Learned for JWST ISIM CV Testing

#	Lesson Learned	Recommended Actions
1	Project personnel touching and/or changing facility configuration (esp. in between tests) must be verified / communicated	<ul style="list-style-type: none"><li>• Test engineer verifies with project before start of test whether the project made any facility changes</li><li>• Test engineer requests that the project informs facility team when items are changed, esp. feedthrough plates and during chamber breaks</li></ul>
2	Stringent leak checking is possible and effective	<ul style="list-style-type: none"><li>• Continue adopting the more stringent leak checking techniques to meet high leak-tight requirements</li><li>• Standard leak check levels were made more stringent for CV2, requiring that measured leaks did not exceed 10<sup>-9</sup> Torr range</li></ul>
3	Helium leak rate detection is a difficult endeavor for high sensitivity measurement requirements	<ul style="list-style-type: none"><li>• Determine the helium background requirement beforehand to gauge whether or not it would be achievable in test</li><li>• Characterize helium background levels and leak tightness of facility prior to executing leak rate measurements</li></ul>
4	Do not assume reliability of the SES LN <sub>2</sub> skid, or any test-critical facility system from one test after another	<ul style="list-style-type: none"><li>• Check programmable logic control (PLCs) before major tests</li><li>• Consider adopting standard operations to include a check-out of major facility systems (i.e. perform a dry-run)</li></ul>



**Questions?**



## Summary of Helium Skid Shutdowns

- Cause #1: low turbine bearing gas temperature alarm
- Cause #2: compressor oil level/temp alarm
- Cause #3: human error
- Cause #4: differential pressure across purifier increased rapidly

CV Test #	Shutdown #	Date	Cause	Pressure Spike	Duration*	He Temp Spike	Duration**
1	1	09/10/13	#1	$4.1 \times 10^{-6}$ Torr	4.0 hrs	52K (+16K)	11.2 hrs
	2	10/05/13	#1	$2.8 \times 10^{-4}$ Torr	5.3 hrs	42K (+15K)	8.5 hrs
	3	10/15/13	#2	$1.1 \times 10^{-4}$ Torr	1.1 hrs	33K (+9K)	14.0 hrs
	4	10/19/13	#2	$9.3 \times 10^{-5}$ Torr	1.1 hrs	32K (+8K)	6.5 hrs
	5	10/22/13	#2	$9.2 \times 10^{-5}$ Torr	6.1 hrs	37K (+13K)	N/A
	6	11/05/13	#2	$6.8 \times 10^{-6}$ Torr	2.1 hrs	N/A (warm-up)	N/A (warm-up)
2	1	06/24/14	#2	$3.0 \times 10^{-6}$ Torr	N/A	199 (<1K)	<15 min
	2	06/26/14	#2	$2.8 \times 10^{-6}$ Torr	N/A	166 (<1K)	<15 min
	3	10/01/14	#3	$2.0 \times 10^{-6}$ Torr	~1 hr	N/A (warm-up)	N/A (warm-up)
3	1	11/7/15	#4	N/A (during pumpdown)	N/A	<0.5K	N/A

\*Duration for pressure to return to  $10^{-7}$  Torr

\*\*Duration for helium shroud average temperature to return to temp before shut-down



# Integrated Science Instrument Module

ISIM is one of three elements that together make up the JWST space vehicle

- Approximately 1.4 metric tons, ~20% of JWST by mass

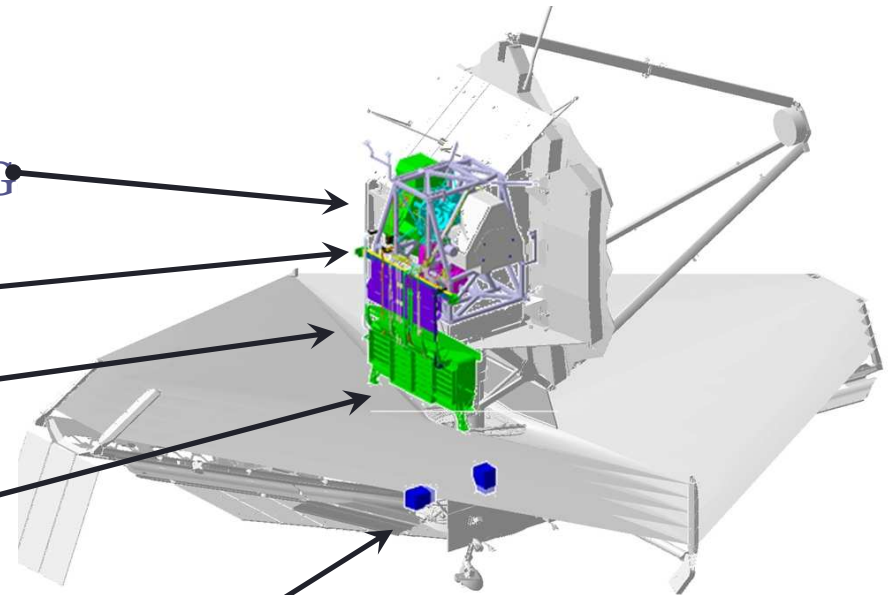
- The ISIM system consists of:

- Five sensor systems

- MIRI, NIRCам, NIRSpec, NIRISS, FG

- Nine instrument support systems:

- Optical metering structure system
  - Electrical Harness System
  - Harness Radiator System
  - ISIM Electronics Compartment (IEC)
  - Cryogenic Thermal Control System
  - Command and Data Handling System (ICDH)
  - ISIM Remote Services Unit (IRSU)
  - Flight Software System
  - Operations Scripts System



## Actions/Issues after CV3 (before Core 2)

Description	Status/Notes	Target completion
Cryopump #4 needs replacement actuator with a manual override, limit switches	Actuator received.	2/26/2016
Cryopump #1 will not pump down it is believed because the rebuilt seals on the main valve actuator are leaking through to the cryo cavity.	Spare parts received.	3/9/2016
Cryopump #6 main valve will not close because main valve actuator is leaking. Actuator will need to be fixed.	Spare parts received.	3/23/2016
Coldheads on cryopump #7 is banging Intermittently.	Coldheads received.	3/18/2016
Cryopump #2 is still banging intermittently: send back to PHPK for evaluation of the drive head & displacers		3/21/2016
The LN2 thermal system could not flood the bottom shroud during the test. At the conclusion of the test the LN2 skid will need to be checked out to determine why the LN2 pump pressure on both pumps is low. Cavitation do to PLC logic. Pump vent valves do not appear to open to prime the pump during start up	PLC changes	4/11/2016
High Pressure GN2 TESCO REGULATOR Fabrication and INSTALLATION		3/4/2016
RV replacement for GN2 backfill system		3/11/2016
Cryopump #7: Oil inside cold-heads	PO placed 02/10/16	3/18/2016





# Helium Skid Shutdowns

Total of one (1) helium skid shutdown

- In an attempt to expedite cool-down helium skid compressor start-up early
- Over-temp shut-down skid
- During pumpdown on 11/7/2015 0:10; minimal effect on the test

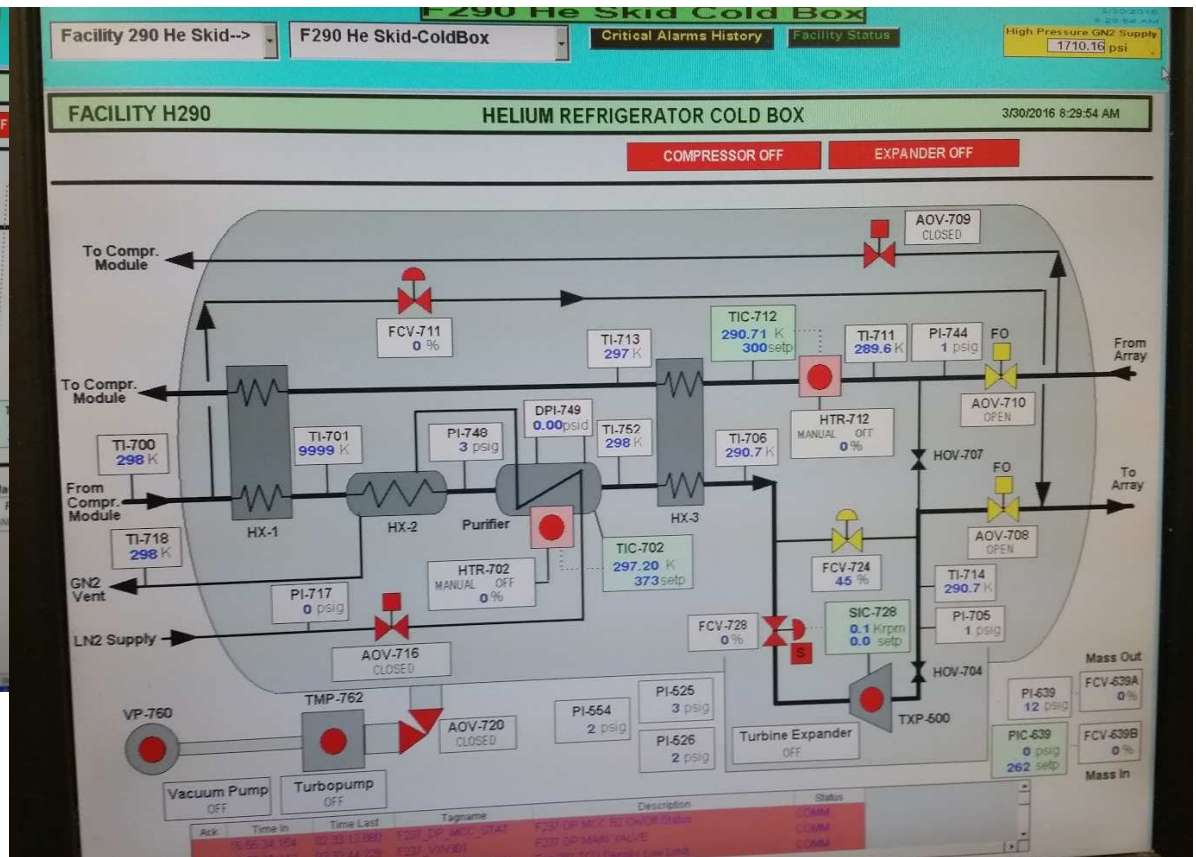
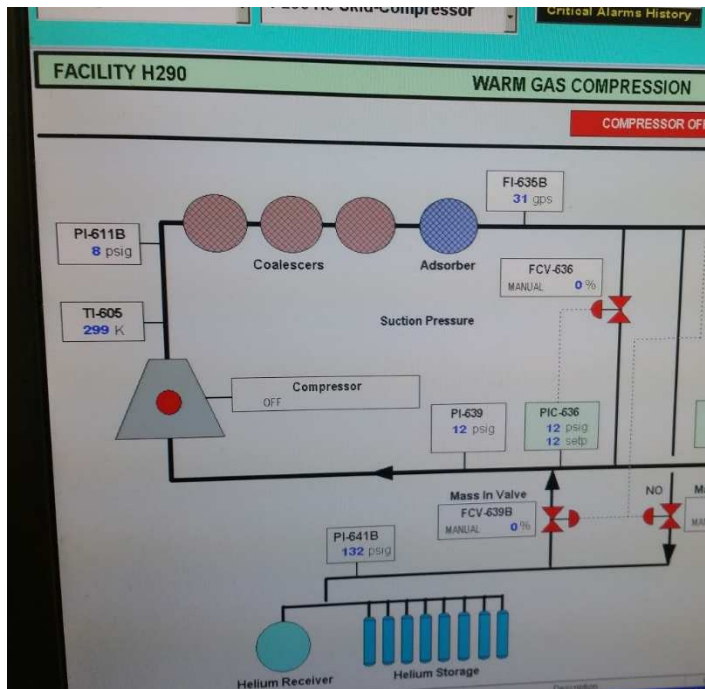
Response to a PR written about this:

*Resolution: The helium skid did not lose power as stated in the PR. Instead, (only) the turbine was shut-down as a result the expander wheel hitting a inlet pressure alarm. The cross-over to turbine mode (from bypass mode) was accelerated because the differential pressure across the purifier was going up rapidly. The valve to the turbine was opened when the inlet temperature to the turbine was at 140K, instead of waiting for it to get to 100K. As a result, the higher inlet gas temperature corresponded to an inlet pressure that exceeded the limits of the expander wheel and consequently shut-down the turbine. In response, the turbine throttle valve immediately failed closed to 0%, and the bypass valve opened to almost 50%. The system (valve positioning) was restored to its configuration (prior to the turbine shutdown) well within 15 minutes. The result was a 10K spike in the expander outlet temperature (helium shroud inlet temperature), but the spike was back to its pre-shutdown temperature within 15 minutes. The effect on the helium shroud average temperatures was less than 0.5K.*

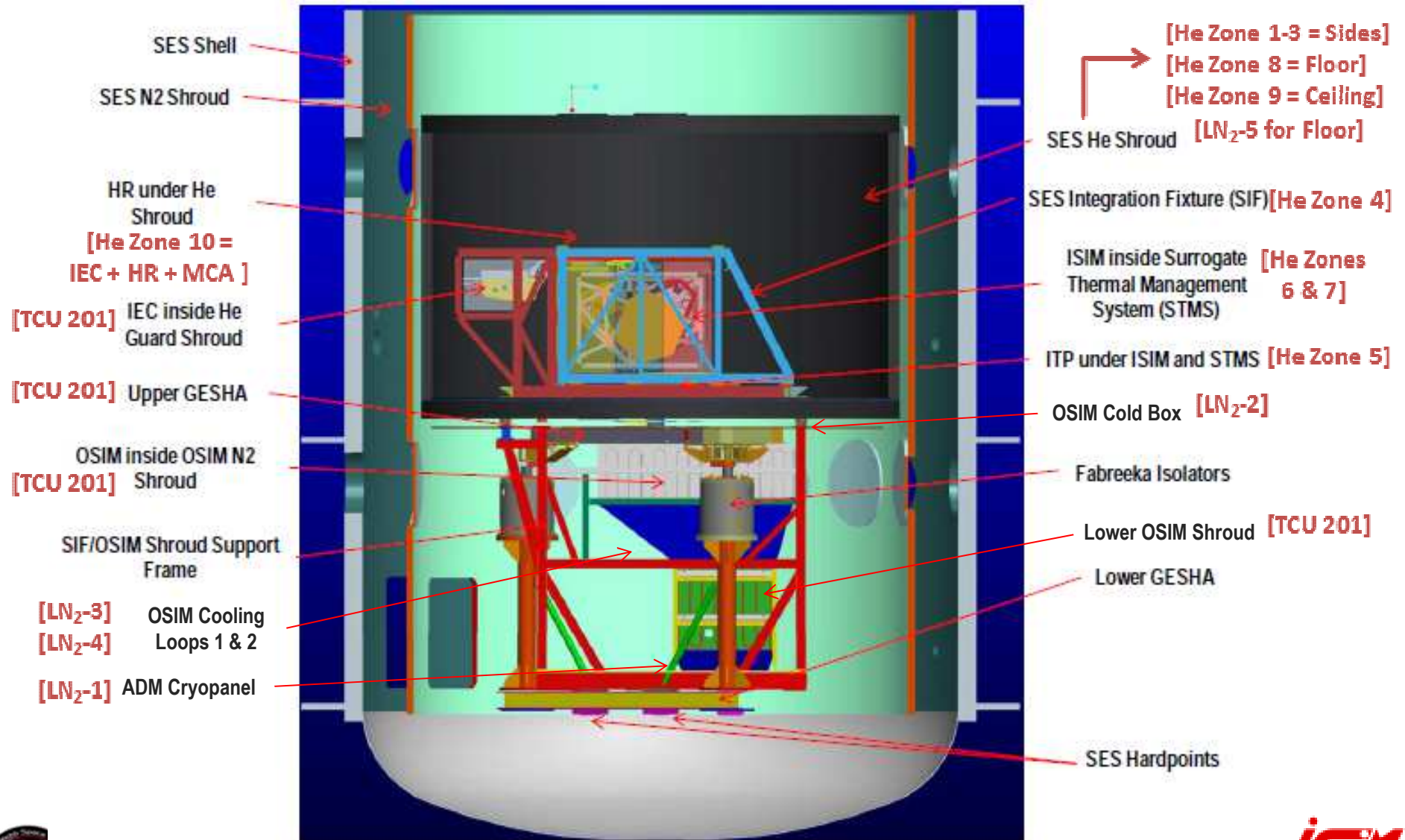


# Helium Skid Shutdowns

Total of one (1) helium skid shutdown during pumpdown on 11/7/2015 0:10

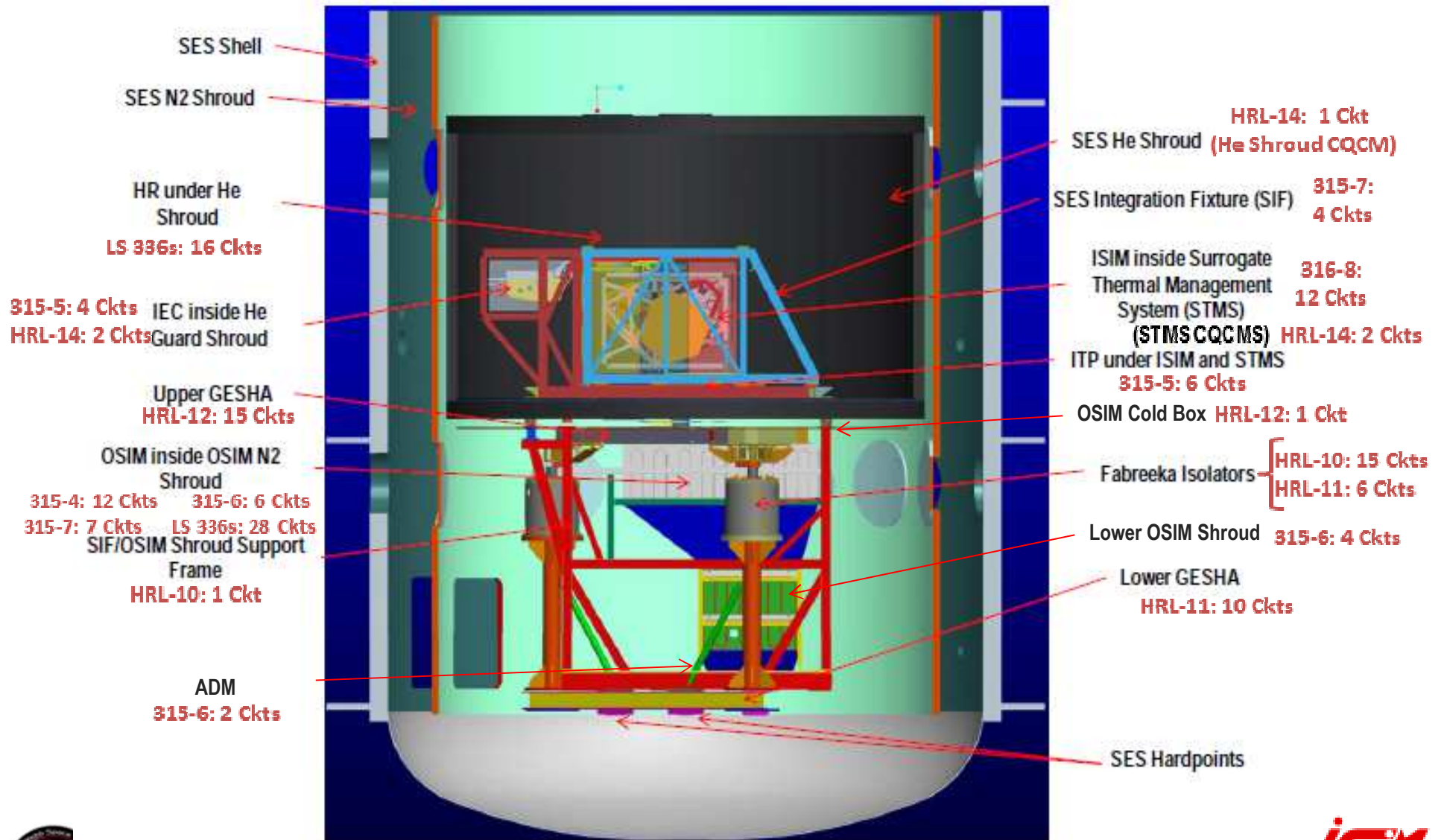


# LN2 & GHe Cryo Zones [TCUs, LN2-only Lines, & He Lines]





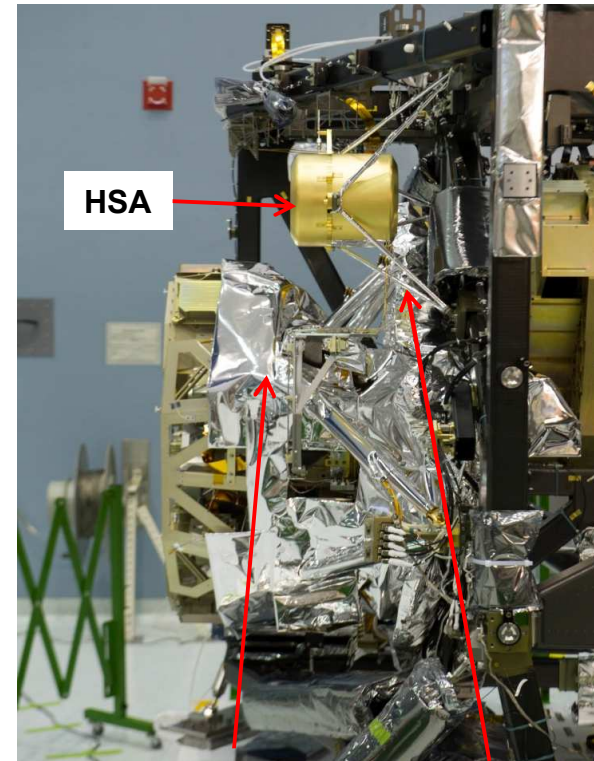
# Heater Zones [Heater Racks]



# Test Configuration for ISIM CV Testing

Notable hardware changes since CV2:

- NIRCam new detectors arrays
- MIRI cooler flight unit (CV2 had flight-like assemblies: cooler lines and heat exchanger stage assembly, HSA)
- NIRSpec kinematic mounts change
- FGS guider detector assemblies
- New focal plane electronics



Refrigerant Lines and Line Support



# Facility Requirements for ISIM CV3

- Thermal Zones
  - SES Shroud ( $\text{LN}_2 \rightarrow \text{GN}_2$ )
  - Helium Shroud (5 GHe circuits)
  - 41 Cryopanels
    - 4 TCUs
    - 6  $\text{LN}_2$ -only lines
    - 5 GHe circuits (re-routing of some zones from CV1)
  - 171 Heater circuits
    - 9 Heater racks
    - 15 LS-336s
- Instrumentation
  - 979 monitoring sensors
    - 2 new diodes for CV3
    - 28 new Cernox sensors for CV3
    - 375 TCs (20 removed from CV2)
    - 604 other sensors
  - 193 heater control sensors

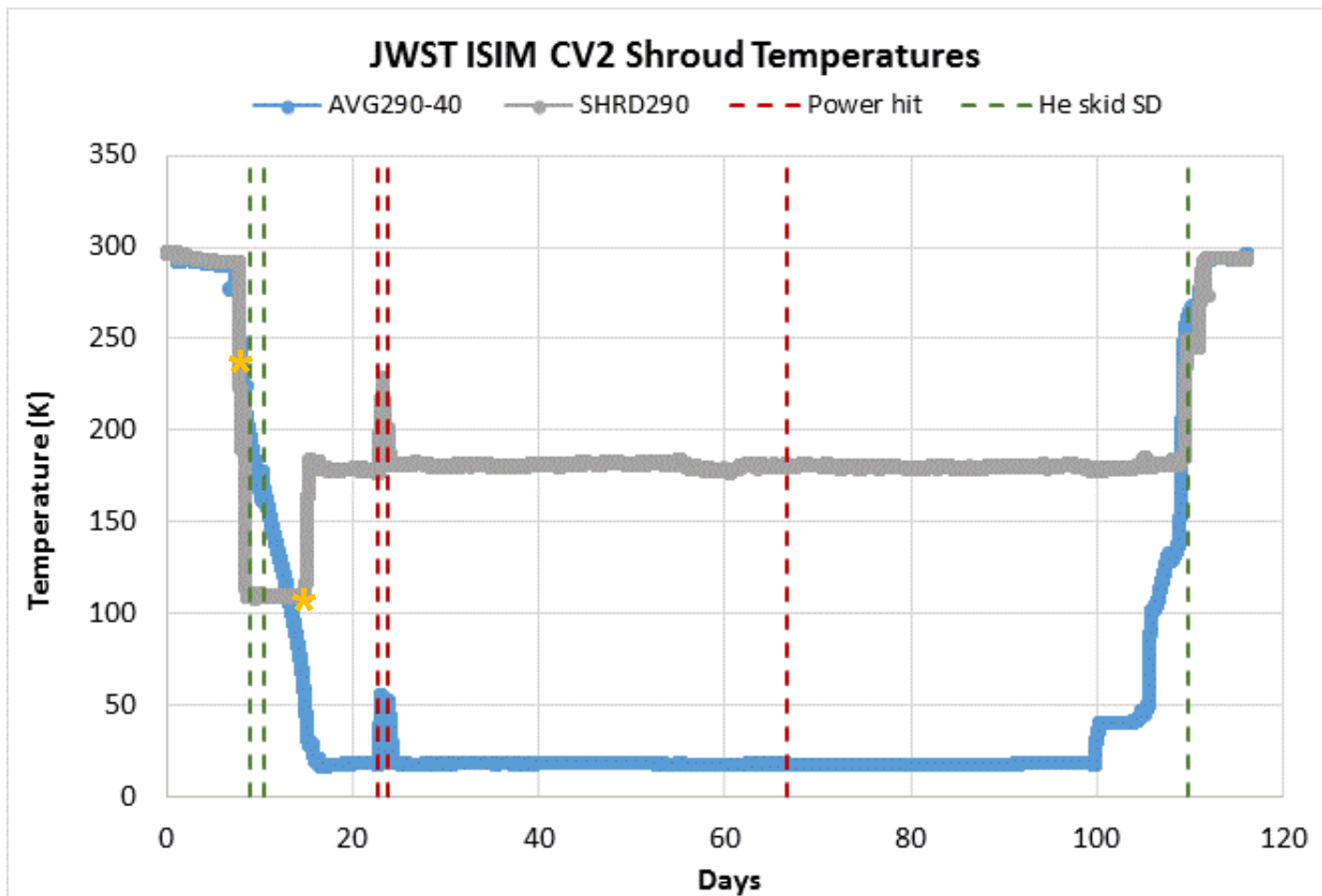
New in CV3	Description
1239-1240	HR GSE Blankets (diodes)
1357-1376	Flight Heat Straps (Cernox)
1580-1587	MIRI GSE Heat Straps (Cernox)





# Shrouds Temperature Performance

At steady state: Helium shroud average achieved:  $18\text{K} \pm 1\text{K}$  ||  $\text{LN}_2$  shroud average:  $180\text{K} \pm 3\text{K}$



\* = Switch  $\text{GN}_2 \rightarrow \text{LN}_2$  (DAY 8 – 6/24/14 03:44)  
 $\text{LN}_2 \rightarrow \text{GN}_2$  (DAY 15 - 6/30/14 22:40)



## Notable Facility Changes Since CV2

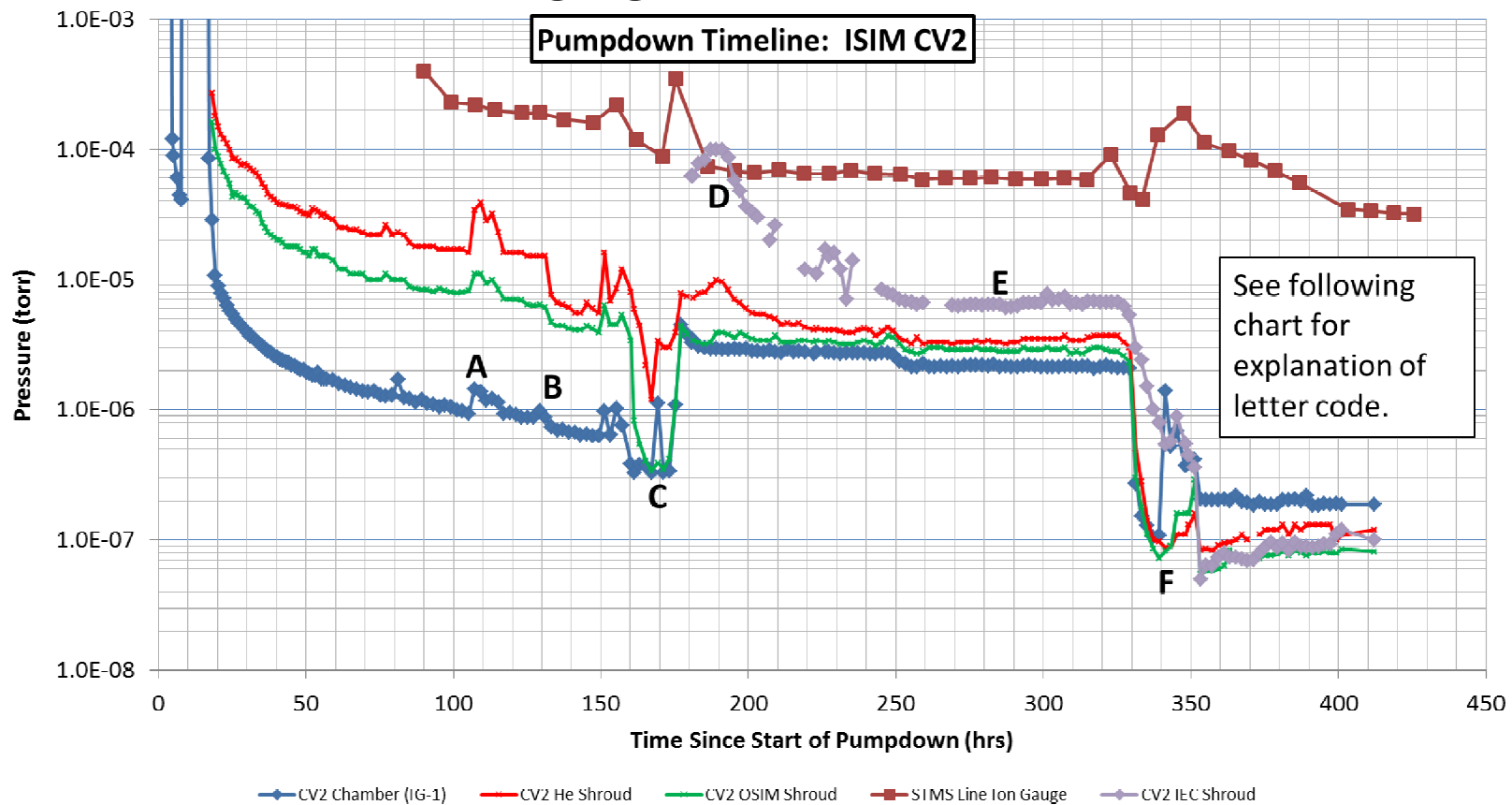
- 1) Redundant micro ion gauge for IEC
- 2) New, calibrated RGA for helium shroud volume
- 3) New cryopumps

PR-	Issue	Updated Status
0391	Micro Ion Gauge #1 (IEC shroud) does not power on and stay on	<ul style="list-style-type: none"><li>• Ion gauge was removed and checked-out</li><li>• A new, redundant micro IG is being provided for CV3</li><li>• Delivered two IEC micro IGs to ISIM for installation on 9/14/15</li></ul>



# Notable Facility Changes Since CV2

## 1) Redundant micro ion gauge for IEC



- A: Response to raising IEC N<sub>2</sub> panel temp
- B: Response to cooling of CQCM lines
- C: Adjustments to facility N<sub>2</sub> shroud
- D: IEC temperature cycle from 273-308 K and back, after which pressure continues to drop as IEC He panels get cold enough to sink water
- E: Pressure in IEC shroud stabilizes, though panels are 130K → 100K, with much lower water vapor pressure than P observed: **suggests an N<sub>2</sub> leak inside IEC shroud; need to check/fix before CV3**
- F: He panels reach temperature for sinking N<sub>2</sub>/O<sub>2</sub>; pressures everywhere plummet

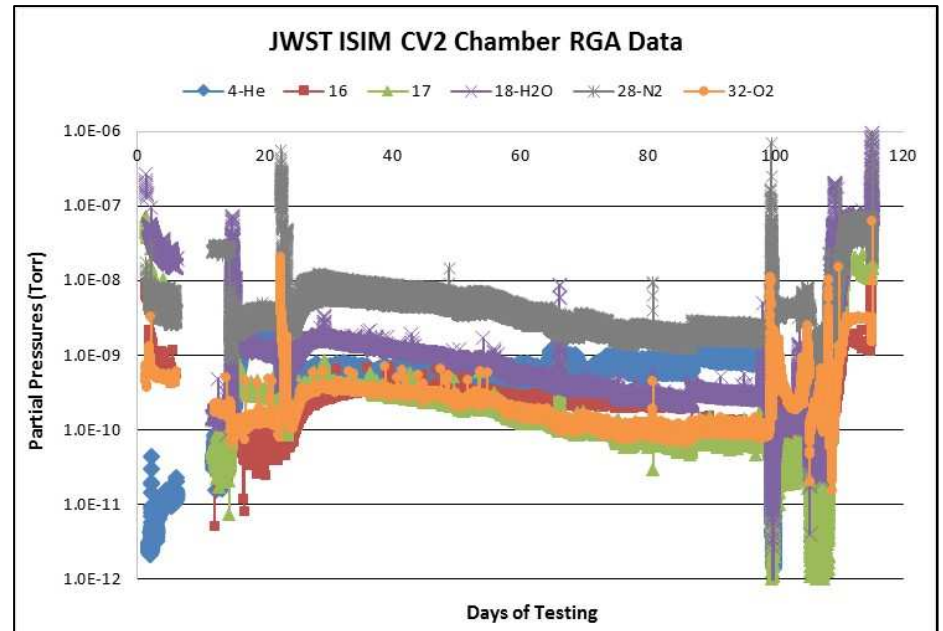
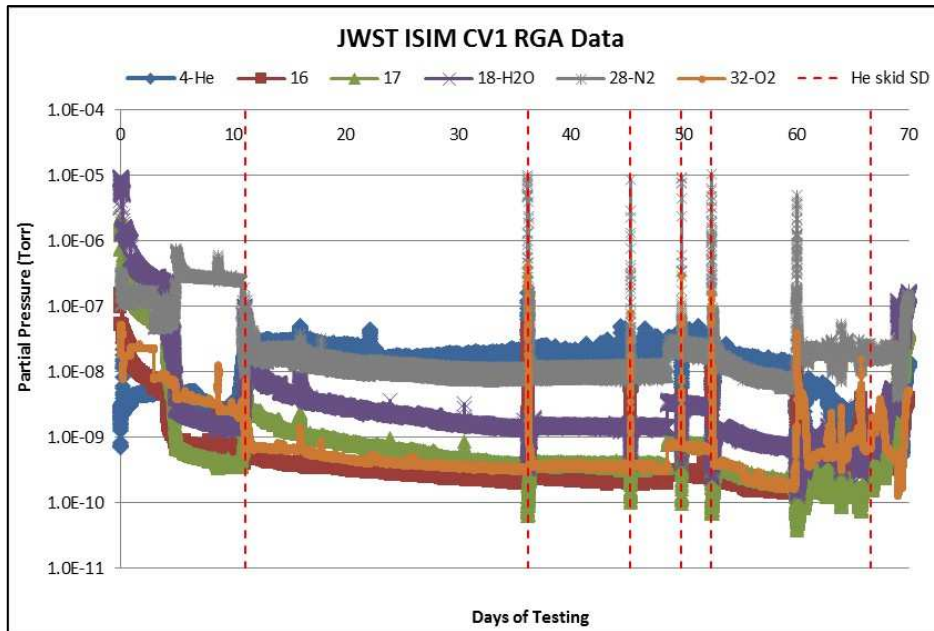




# CV1 vs. CV2 Chamber RGA Detection Levels

ISIM CV1: Chamber RGA detected helium levels around  $1.5 \times 10^{-7}$  Torr

ISIM CV2: Chamber RGA detected helium levels around  $1.0 \times 10^{-9}$  Torr



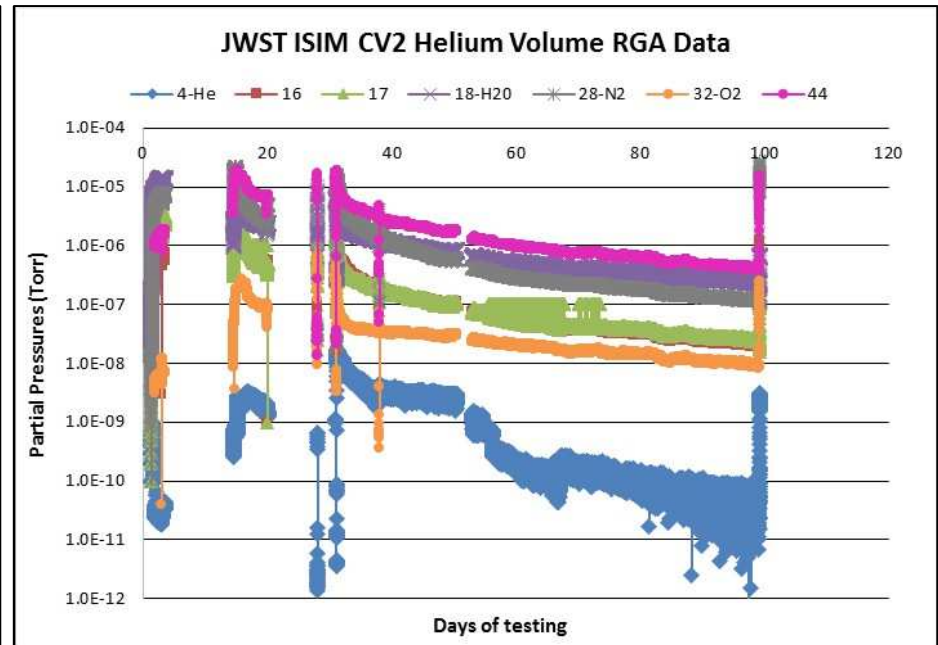
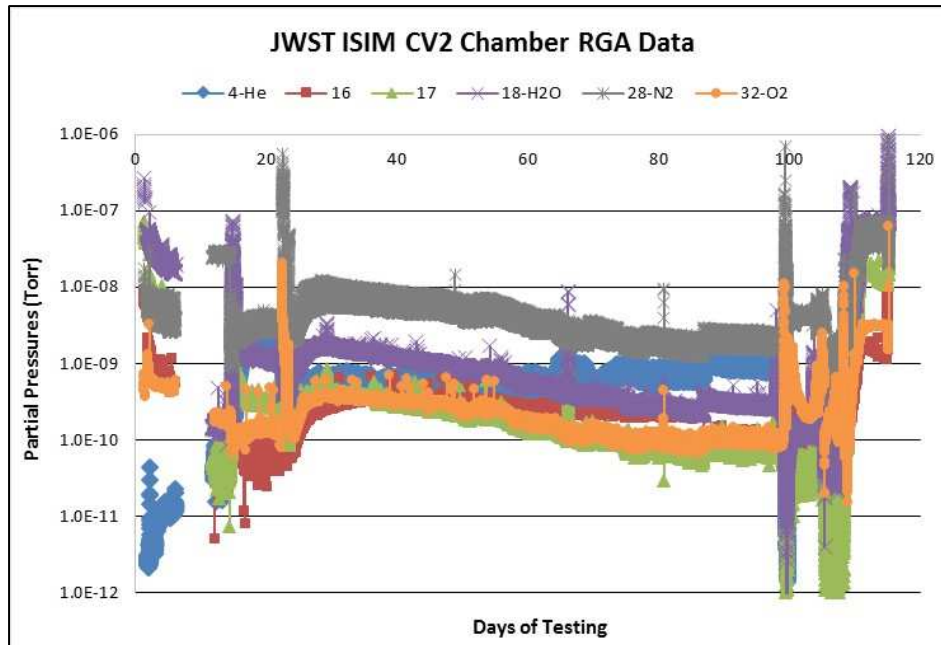
Levels of detected helium using chamber RGA decreased by almost two orders of magnitude from CV1 to CV2



## CV2 Chamber RGA vs. Helium Volume RGA Detection

ISIM CV2 Chamber RGA detected helium levels around  $1.0 \times 10^{-9}$  Torr

ISIM CV2 ISIM/STMS volume RGA detected helium levels consistently  $<1.0 \times 10^{-8}$  Torr



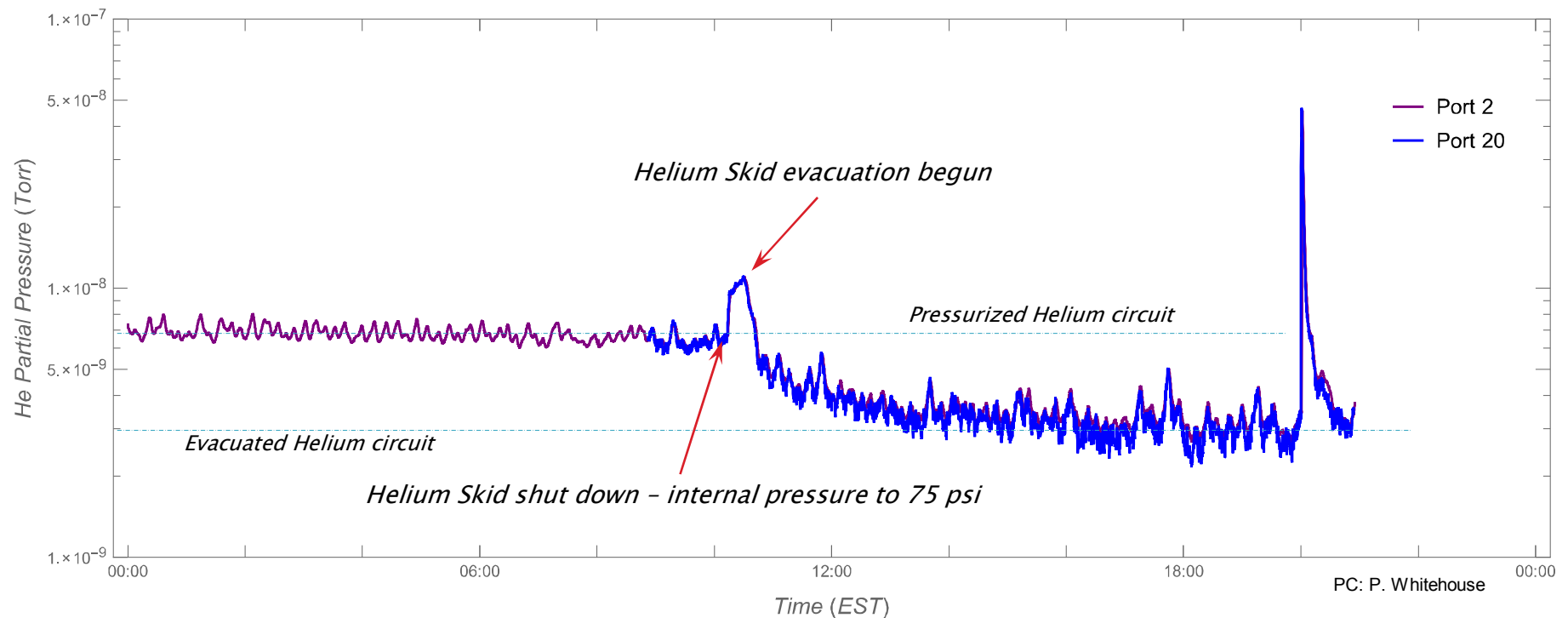
ISIM CV2 Chamber RGA detected helium levels were more consistent throughout the test, whereas the detectable helium levels using the ISIM/STMS RGA slowly decreased throughout the test

Both in CV1 & CV2, the difference between the total chamber RGA partial pressure readings & the chamber IG pressure readings was  $\sim 2.0 \times 10^{-7}$  Torr higher pressure (lower vacuum) on the IG



# Notable Facility Improvements CV1 → CV2 → CV3

## Average Daily Helium Readings During Warm-Up



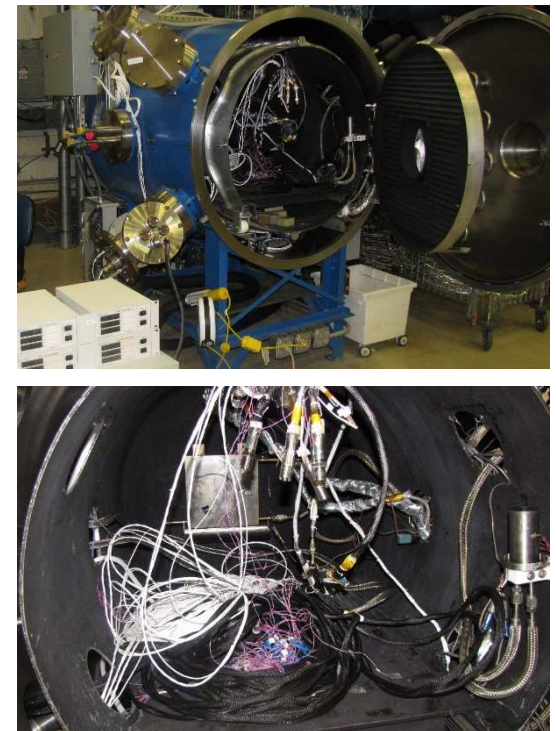
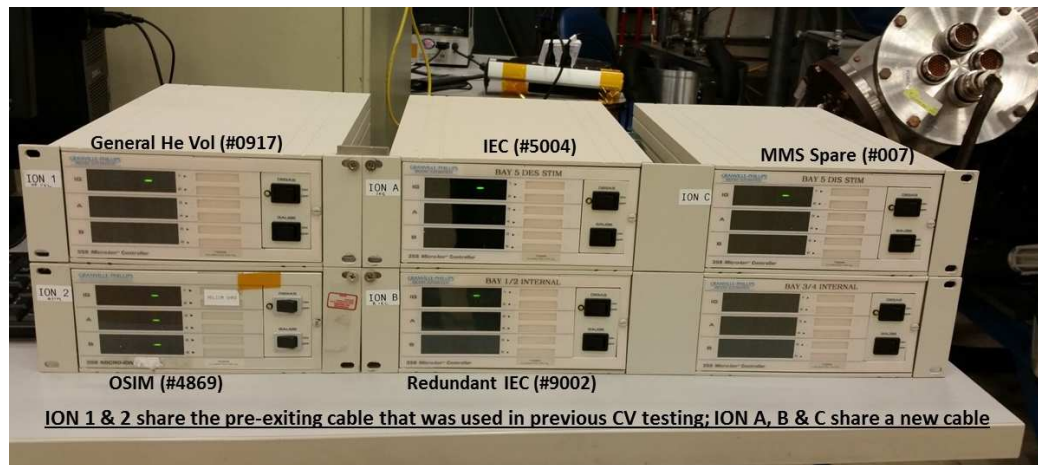
Readings between the two RGAs are consistent at warm temperatures



# Notable Facility Changes Since CV2

## 1) Redundant micro ion gauge for IEC

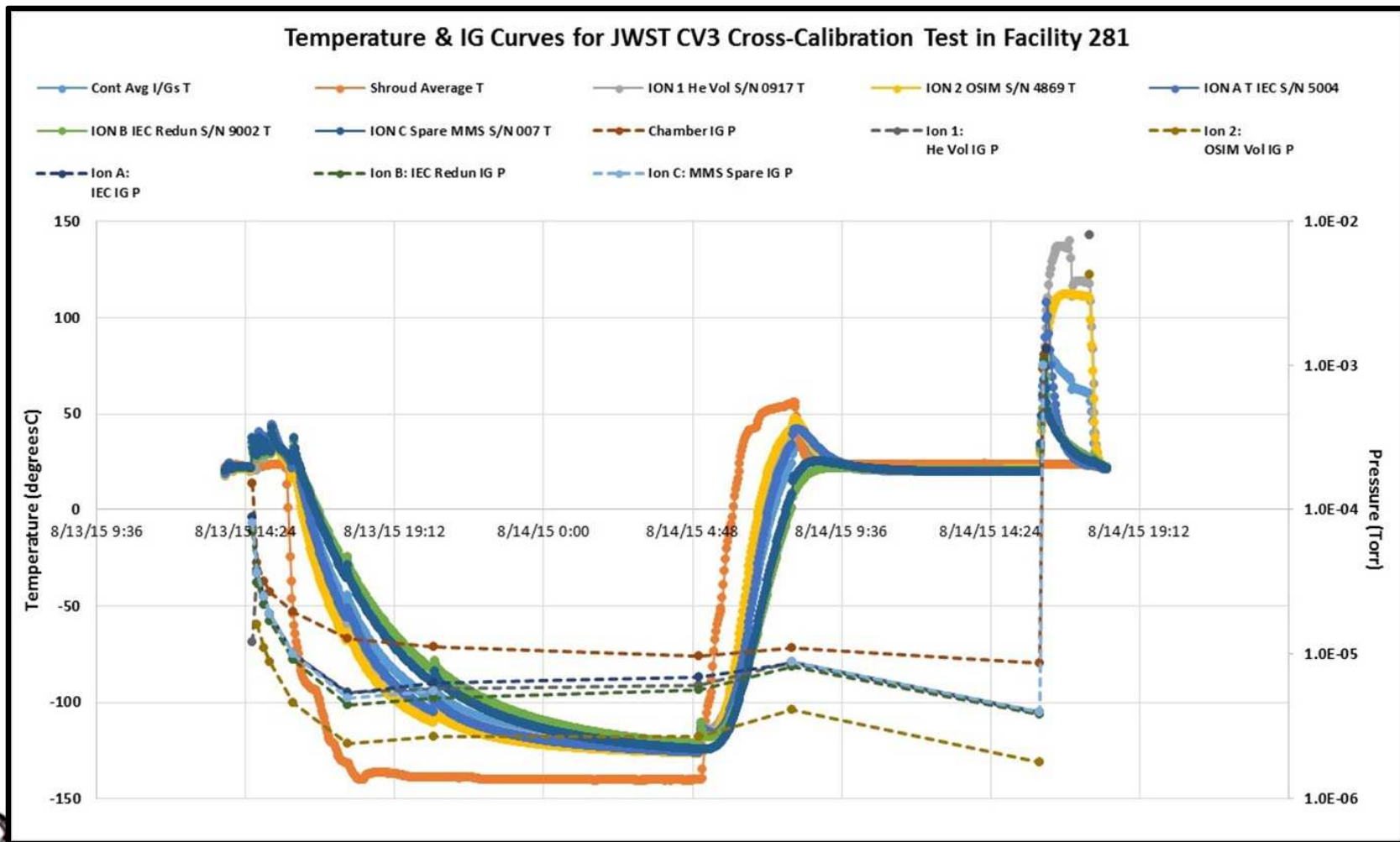
- During check-out of the CV2 IGs, it was discovered that the extension used for the IEC IG was the root cause for the erratic and unreliable readings (per the spec sheet, maximum cable length allowable is 50')
- Cross-calibration of existing and new harnesses (+1 new redundant IEC micro IG) was performed in Facility 281





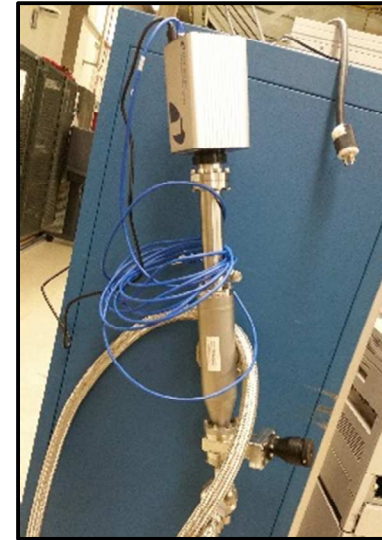
# Notable Facility Changes Since CV2

## 1) Redundant micro ion gauge for IEC



## Notable Facility Changes Since CV2

- 1) Redundant micro ion gauge for IEC
  - 2) New, calibrated RGA for helium shroud volume
  - 3) New cryopumps
- MIRI requirement: 6.2 K (-266.8°C) at the instrument
    - 2-stage cooler system
    - Accurate heat map required during environmental testing
  - Issues during CV1 & CV2
    - Measured heat loads to cooler from MIRI higher than expected
    - Presumed cause is higher levels of helium in chamber

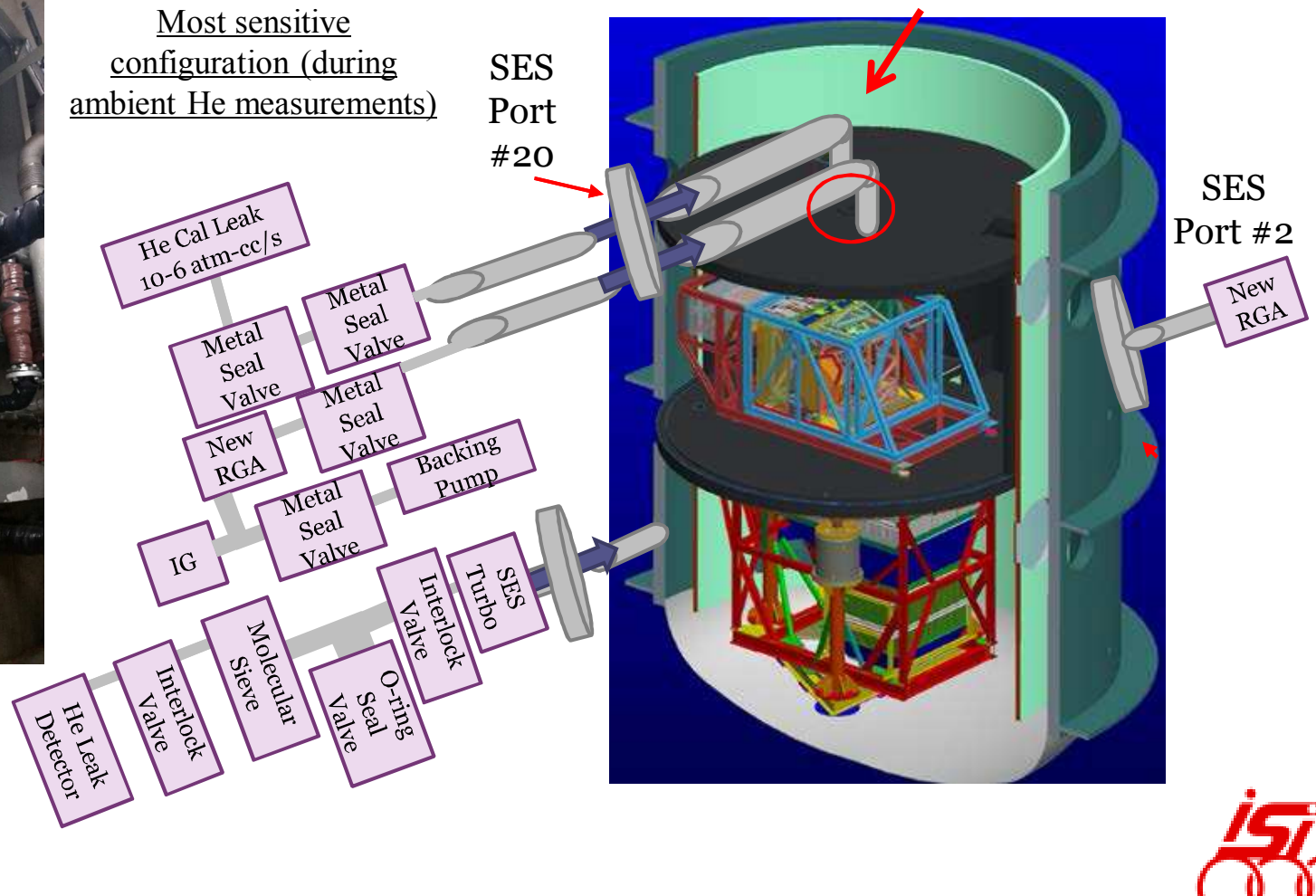


# Notable Facility Changes Since CV2

## 2) New, calibrated RGA for helium shroud volume



Most sensitive configuration (during ambient He measurements)



Entrance of two (1/2" SS line) tubing from chamber port thru the hole on the roof of He Shroud

SES Port #20

SES Port #2  
New RGA



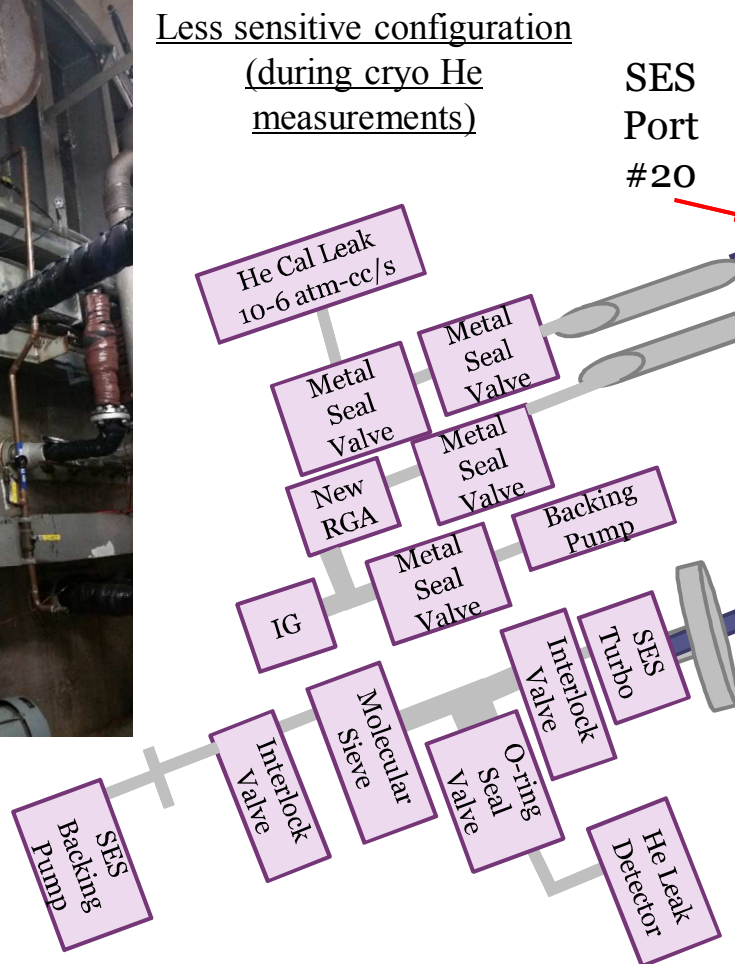


# Notable Facility Changes Since CV2

## 2) New, calibrated RGA for helium shroud volume

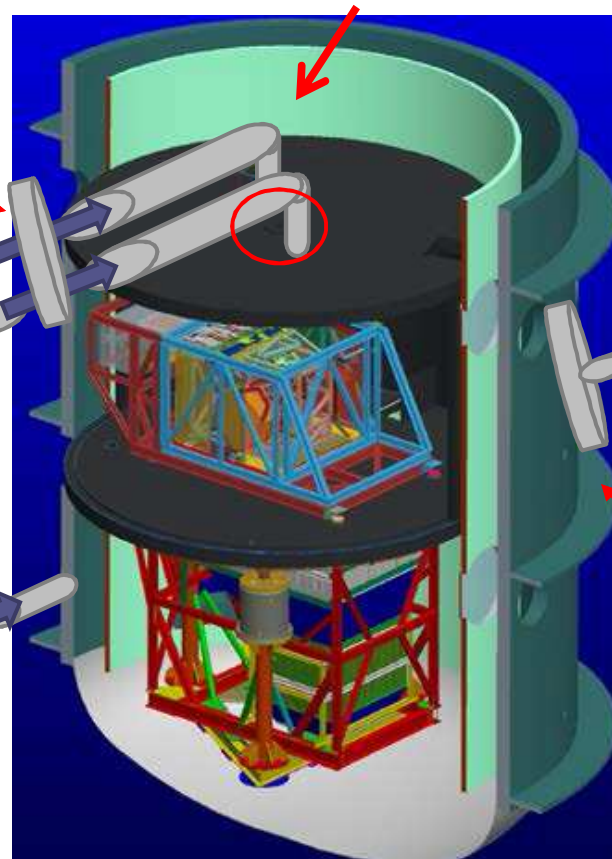


Less sensitive configuration  
(during cryo He measurements)



SES Port #20

Entrance of two (1/2" SS line) tubing from chamber port thru the hole on the roof of He Shroud



SES Port #2  
New RGA



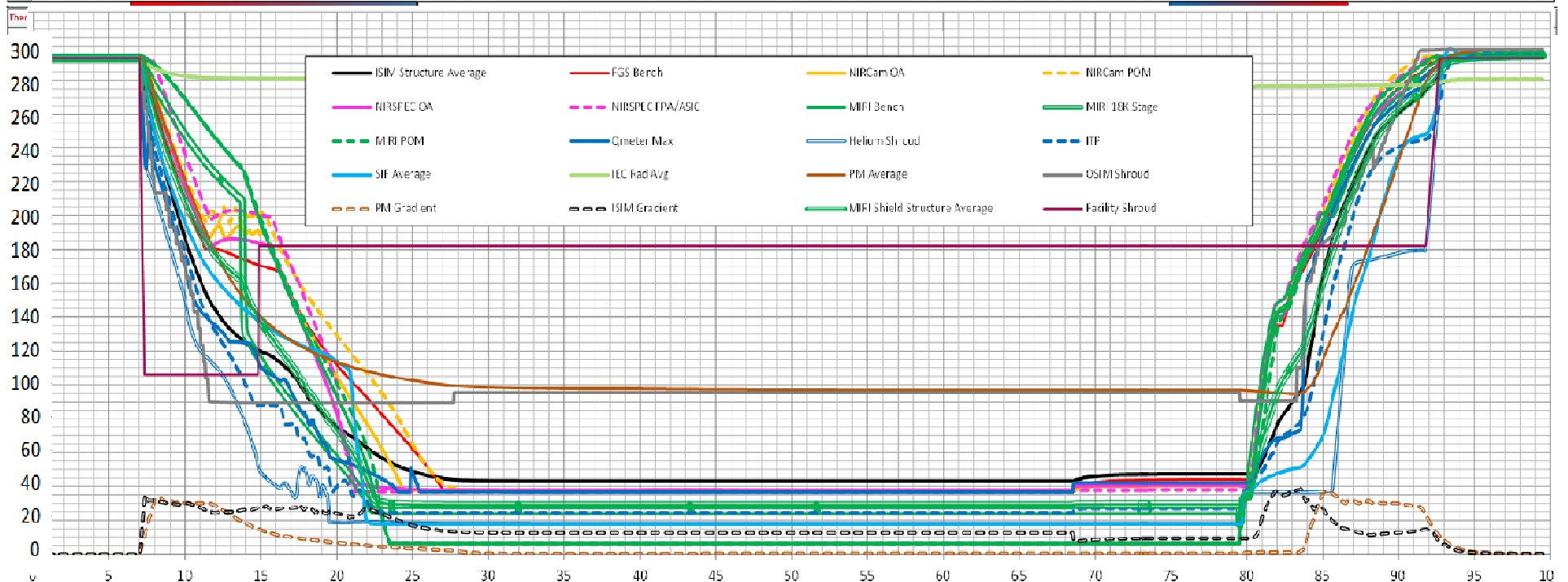
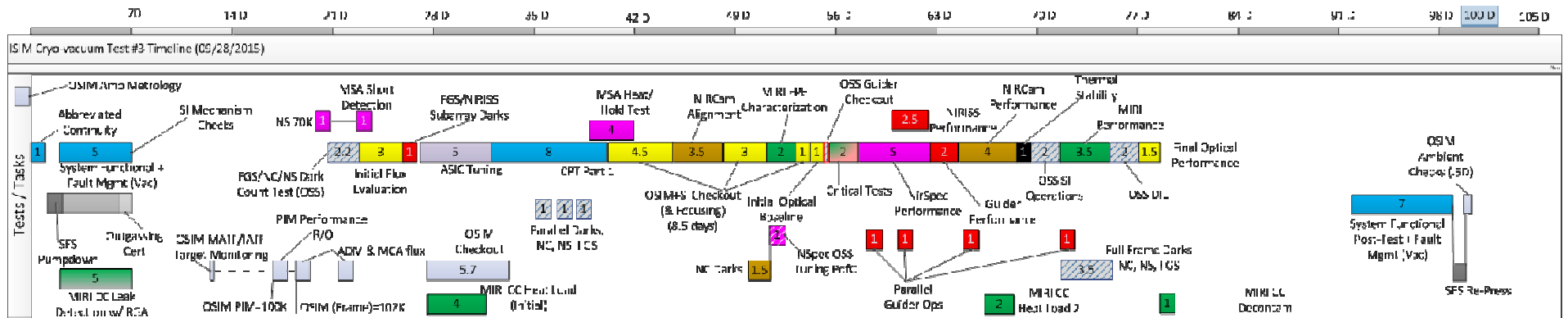


## Notable Facility Changes Since CV2

- 1) Redundant micro ion gauge for IEC
- 2) New, calibrated RGA for helium shroud volume
- 3) New cryopumps
  - Cryopump #2 made intermittent banging noises during CV2
    - Oil found on coldheads
    - Contaminated coldheads shipped to PHPK
    - PHPK investigated and replaced coldheads
  - Cryopump #4 & #6 were replaced
  - Cryopump #3 was rebuilt
  - Cryopumps started testing/check-out October 1, 2015: test for 13 days at cold pumping on itself



# CV3 Test Profile



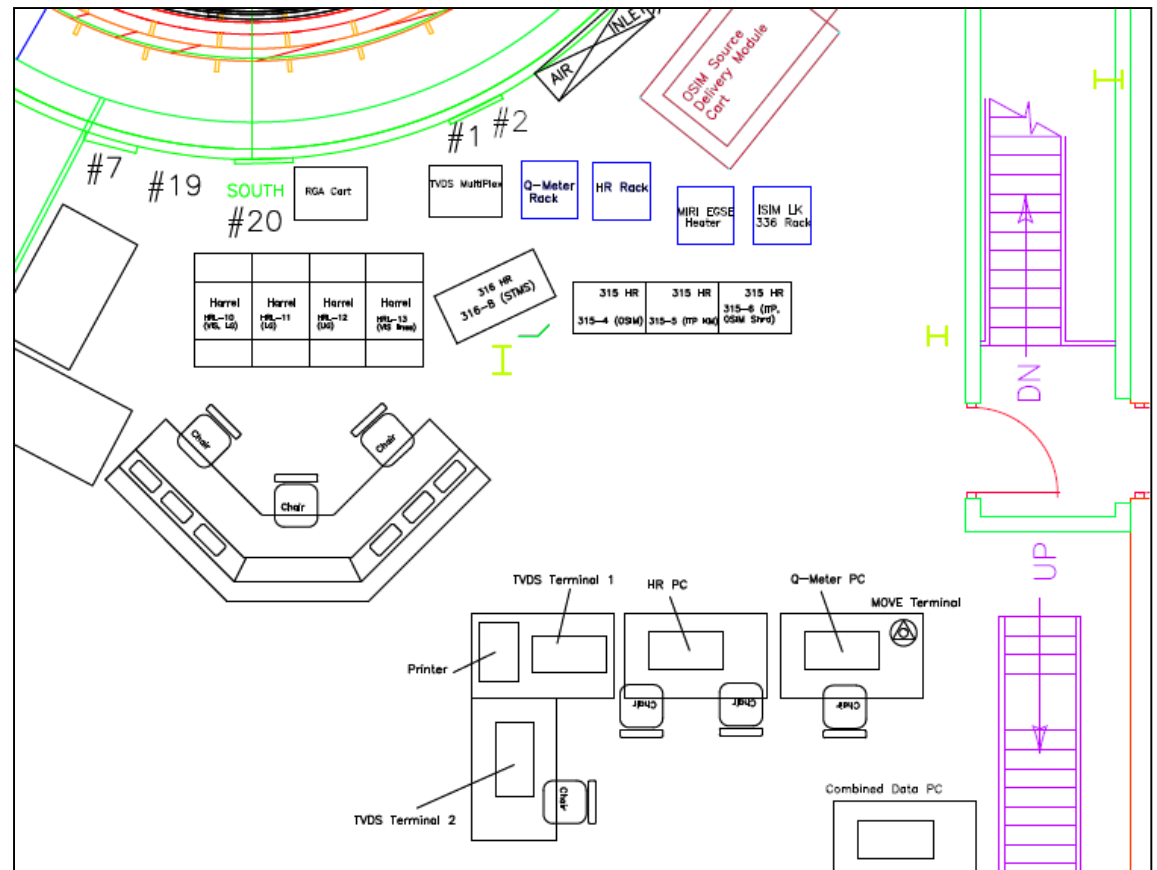
## SES Facility LN2 Valve Failure

- **An LN2 valve was discovered in a failed open position. This was flowing LN2 to the GN2 compressor. The excess LN2 needs to be dumped from the system, which requires securing the LN2 supply. This takes the chamber cryopumps off-line.**
- Resolution: the excess LN2 was vented from the system while the chamber pressure was maintained, using only the chamber turbopump, at  $\sim 2 \times 10^{-4}$  Torr. After the GN2 heat exchanger and LN2 lines were sufficiently drained on Saturday 10/31/15, the cryopump LN2 valve was made operational again. The facility is back to normal operation. The root cause of the GN2 heat exchanger flooding event was determined. The GN2 skid was shut-down and locked-out to allow a Proconex technician to troubleshoot and recalibrate a faulty positioner that indicated it had failed. In doing so, all the GN2 skid valves assumed their failed (open/close) safety position, and all pressure control loops were disabled. As a result, the heat exchanger GN2 inventory control loop which maintains a pressure of 60 to 70 PSIG was disabled allowing for the GN2 pressure in the heat exchanger to drop to 0 PSIG. Without there being pressure in the exchanger, the LN2 from the vent line filled up the exchanger. Once power was restored to the GN2 skid the pressure in the exchanger was reestablished without further incident.



# Facility Preparation Status

- Data Acquisition
  - 3 TVDS stations set-up
    - 2 at SES
    - 1 in ICC for JWST (B29/R156)
  - Q-meter
  - Harness Radiator
  - TCR forms completed
  - Stand-alone systems in progress
    - CQCMs (x2)
    - RGAs (x2)
- Facility PMs have been completed, and none are scheduled for the duration of the CV3 test





# Facility Preparation Status

- Documentation
  - Safety Evaluation Form
    - No changes from CV2
    - Request has been made to JWST to sign CV3 form, which will be added to the folder of safety evaluations for all the hardware in previous JWST tests
  - 549 procedure
    - Send out for review Tuesday, 10/13/15
    - Will collect signatures by Tuesday, 10/20/15
- Helium skid
  - Clean-up will start with pumping and purging when all hook-ups are completed
  - 20 He gas bottles being ordered for the SES
  - Rental generator contract for CV3 duration: arrive & install 10/13/15, electrically check-out and power transfer check on 10/15/15

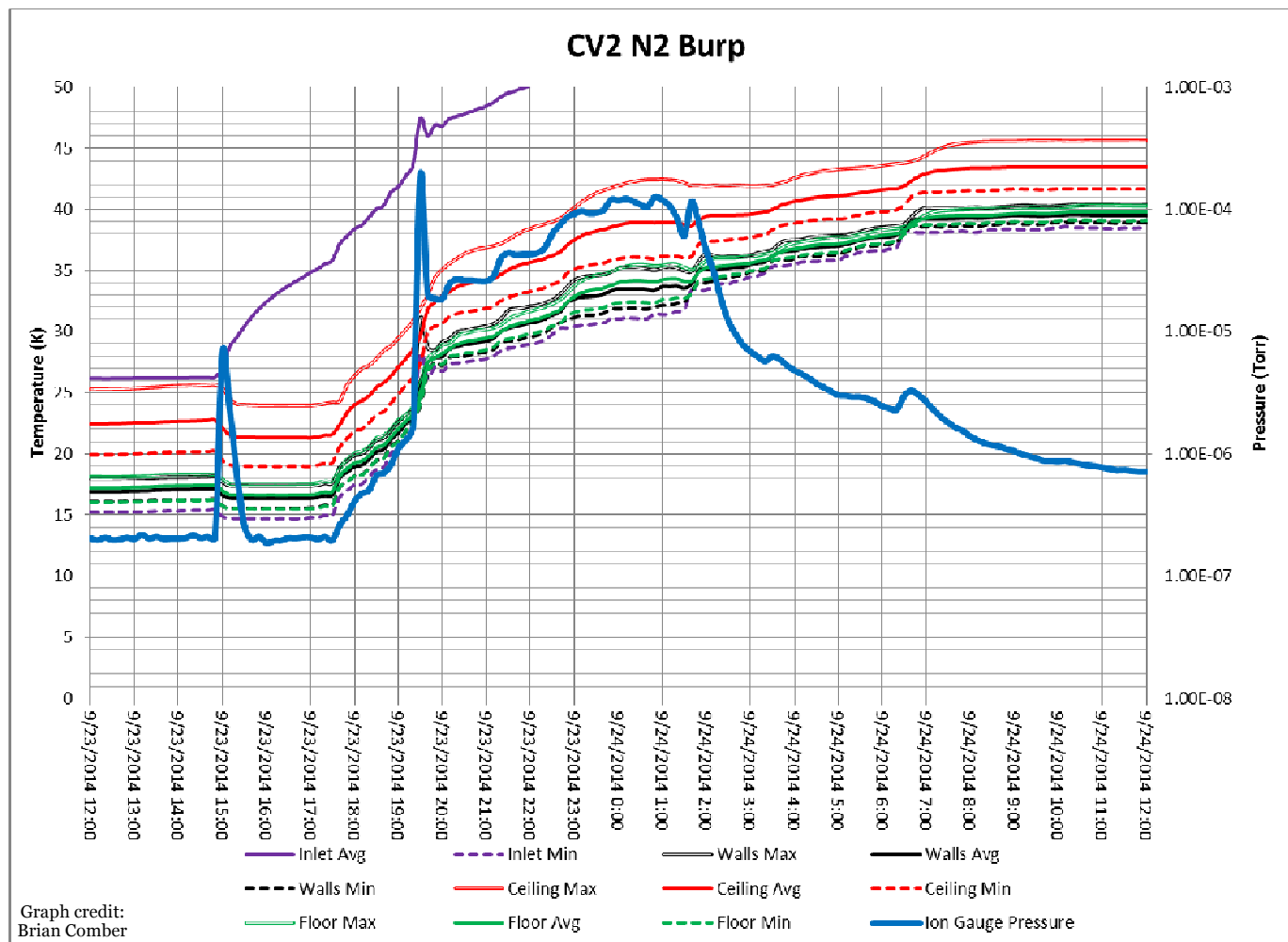


## Top Facility-Related Risks for JWST

Description	Mitigations
Helium Leaks: MIRI Cooler heat load from CV1 was high & He measurements not sensitive enough in CV2	<ul style="list-style-type: none"> <li>Standard leak check levels were made more stringent for CV2 <ul style="list-style-type: none"> <li>Measured leaks to <math>10^{-9}</math> Torr range</li> <li>Will use sniffer capable of measuring <math>10^{-11}</math> Torr range to measure region that cannot pull vacuum to leak check</li> </ul> </li> <li>Developed extensive calibrated RGA plan with MIRI team</li> </ul>
Nitrogen leaks	<ul style="list-style-type: none"> <li>Purge lines to SIs in He volume <ul style="list-style-type: none"> <li>Leak check purge lines</li> <li>Disconnect, evacuate and cap after pumpdown</li> </ul> </li> <li>Nitrogen shroud will operate in GN2 mode at steady state</li> </ul>
Power outage	<ul style="list-style-type: none"> <li>Will verify He skid UPS performance</li> <li>All JWST critical equipment on UPS</li> </ul>
Chilled water outage	<ul style="list-style-type: none"> <li>FMD 24/7 support</li> <li>Developed chilled water outage response plan &amp; will communicate plan with JWST</li> </ul>
New cryopumps	<ul style="list-style-type: none"> <li>Test for 13 days</li> </ul>



# The Nitrogen (and Oxygen) Burp



**Estimate of gas released: up to 700 g, or 0.65 torr, if released suddenly into the chamber → thermal effects would be significant**



## Compared to OSIM Nitrogen (& Oxygen) Burp

